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NASA-USRA ADVANCED SPACE MISSION DESIGN PROJECT

2010: A CONCEPTUAL DESIGN FOR A MANNED, ROTATING GEOSYNCHRONOUS SPACE STATION

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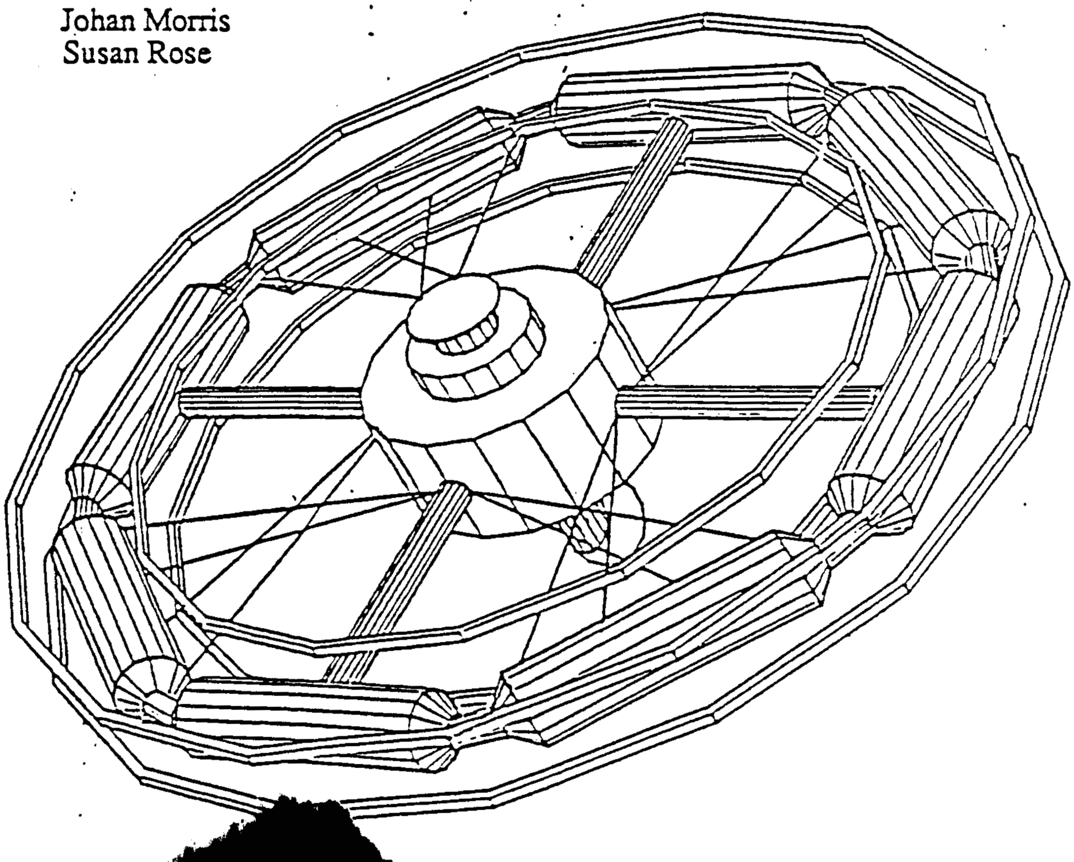

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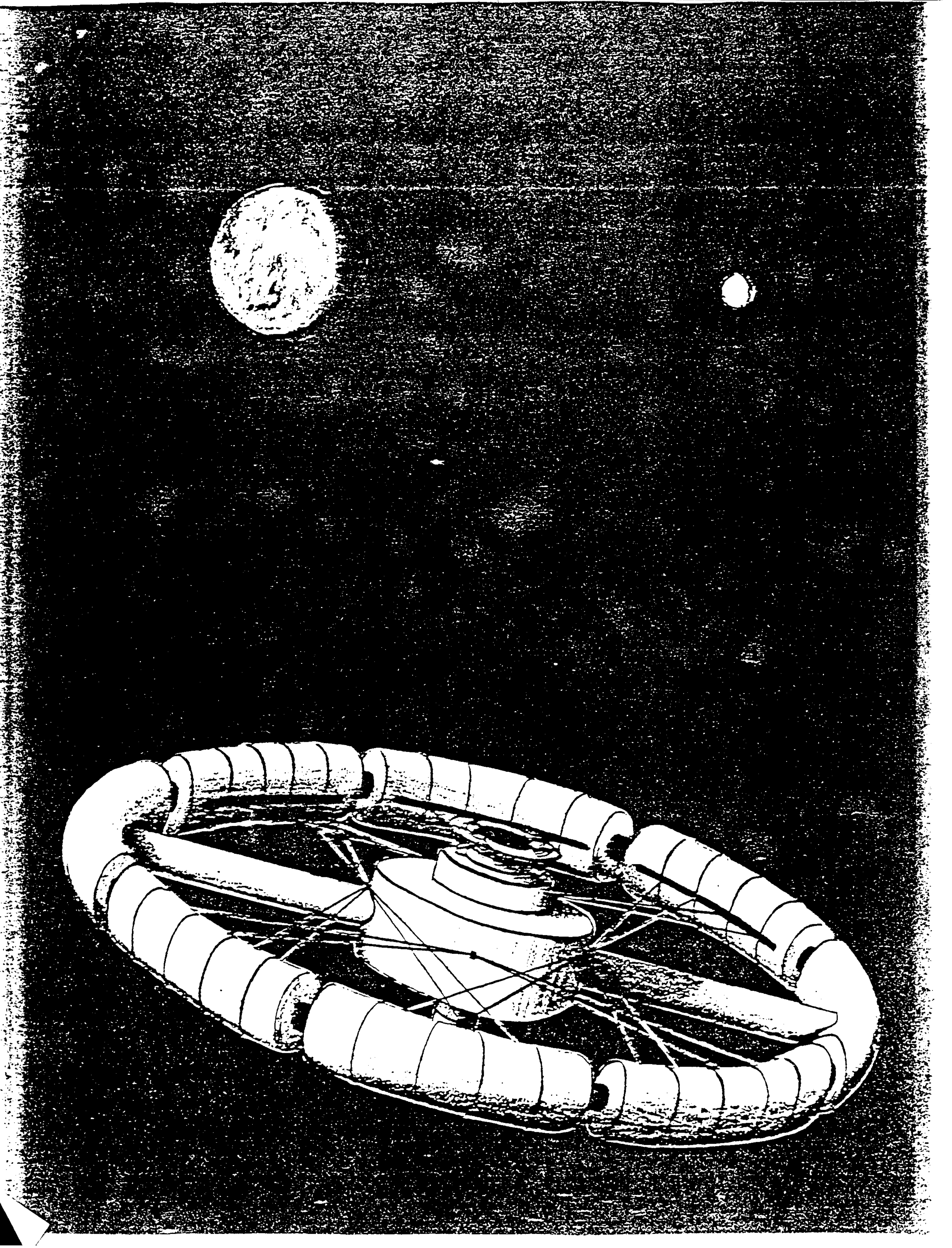

Introduction

The present preliminary design of the manned rotating Geosynchronous Space Habitat (GSH) was a result of three semesters of work in the Advanced Space Mission Design class. The GSH was designed around several major criteria: it must provide a number of services; it must be manned for at least six month intervals; it must serve as a launch point for interplanetary missions; and it must provide a comfortable habitat for the astronauts. Other criteria included the use of modularity and present technology, while maximizing safety and minimizing cost.

These criteria have been used throughout the three semesters. The revised design of GSH is a result of further exploration and the development of new approaches. The inclusion of artificial gravity became a design criteria for the 1985 fall semester. All areas have been expanded upon, some extensively. The following report describes, in brief, the present station. This effort is a preliminary conceptual design.

Justification for the GSH

The proposed Geosynchronous Space Habitat (GSH) would require a 10 to 12 billion dollar financial investment, as well as countless man hours of intensive research, design and development. In the light of the present U.S. economy, with a 2 trillion dollar national debt and an annual 200 billion dollar foreign trade deficit, such a project seems doomed. However, a second look opens the door to a multitude of scientific, commercial, economic and political reasons for continuing the progression of manned space exploration, in particular, with the GSH. The following justification process will pass from a geosynchronous based platform to a permanently manned space habitation having an induced artificial gravity of 0.8 g's.

The demonstrated communications, scientific and security value of the geosynchronous earth orbit (GEO) provide a compelling case for the preservation of this important but limited resource. Presently over 200 geostationary satellites exist along with a comparable number of debris such as discarded apogee kick motors, spent rocket upper stages and satellite parts. Having an average life time of approximately ten years, these satellites will all be in need of attitude control propellent and or repair by the year 2000.

Therefore, as noted by Lemoine and Morris (1986, Appendix A), orbital maneuvering vehicles (OMV's) based in GEO could provide the satellite refueling, repair and debris clean up: at six times less expense than the same mission originating from LEO. To do this requires a GEO platform or station to be used as an OMV refueling base and a storage facility for the debris and for the satellites which need extensive repairs beyond the capability of the OMV's.

Satellite servicing, the most important aspect of the platform, provides an immediate economic return on the initial investment. "Preliminary estimates indicate that two GEO based OMV's performing twenty satellite servicing missions annually, would save 1.6 billion dollars in satellite replacement costs during the first year of operation." (Lemoine and Morris, 1986,

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Acknowledgements

The following people have contributed to this document. Their time and dedication to this project are greatly appreciated. We would also like to thank the group of students who started this project a year and a half ago.

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NASA / Ames: Robert MacElroy
Delbert Philpot

University of Colorado, Boulder: Marvin Luttges
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The following are lists of students who have participated in the Aerospace - 595 Space Habitation Design class which is the NASA/USRA University Advanced Space Mission Design Project.

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Overview

This design of a manned, rotating, geosynchronous space station, is a result of the NASA / University Advanced Space Mission Design Project managed by USRA in which the University of Colorado, Boulder is participating along with other universities around the country. Several more complete and detailed papers, including that presented at the annual project design review in July of 1985 at the NASA Kennedy Space Center, have been written about this design effort.

The following activities have occured over the past year:

- Presentations to:
  - The National Commision on Space
  - Senator Harrison "Jack" Schmitt
  - Astronaut Marsha S. Ivans
  - NASA / Ames sponsor Robert McElroy
- 3 C.U. representatives went to the Architectural Concepts Review at NASA / Ames Research Center
- 1 C.U. representative went to NASA / Langley to research the NASA CAD software
- 3 C.U. representatives went to NASA / Langley to present CAD usage in design efforts
- 7 AIAA papers were presented at the annual student paper conference in Ames, Iowa concerning different sections of this design course
- 2 design reviews were presented to area industry representatives
- Articles for Aerospace America and Student Journal of Aeronautics were recently submitted

Also, please note that the most recent design has four torus arms, instead of two, and that the eight habitation modules are cylindrical and not curved.

Appendix A)

The second major potential use of the platform is for the scientific community. Possible sciences to be performed include astronomy, astronautics, astrophysics and astrobiology. More specifically this space platform lends itself to high resolution observation (remote sensing) of the earth, ocean and the atmosphere; weather prediction and monitoring; and the observation of the earth's resources and environment.

Another large area of demand, particularly to commercialization, is communication systems. The platform can be used as a relay communication center as well as for communication with deep space probes and vehicles. Other uses call for the platform to: support large complex payloads; alleviate congestion of the "popular" orbital GEO arcs (such as those above Europe, Japan and the United States) by having multi-science and multi-user satellite platforms; facilitate multiple reuse of frequencies in the 1 to 10 GHz band; and provide a technological proving ground for robotics and telepresence. These are only a few of the uses of the platform. The next question to be addressed is: Does a permanently manned platform, i.e. a space station, increase the cost effectiveness of the platform?

A platform can be operated with any of the following three modes: delayed response, telepresence, and physical human presence. The use of delayed presence, also known as automated robotics, will certainly be an important mode on the platform or space station. However, this method is severly limited when considering science and commercial needs. Telepresence, the use of real time communications, visual display, and remote control to provide an operator on the earth's surface the capability to carry out complex operations on the platform or space station, offers such advantages as efficiency, and collaboration with experts. This mode of operation is also deficient in terms of the limited immediate expansion and flexability. The Space Applications Board suggests that "considerable development will be required to produce a teleoperator with scanning and focusing eyes, facile arms, and pressure sensitive fingers to perform complex on-orbit assembly."(Practical Applications of a Space Station, Appendix A)

Today's technology, automated robots or telepresence, can not imitate the unique capabilities of the trained mission specialists. Humans, given that they are trained, skilled, and experienced, can provide a real-time observation and interaction in an adaptive mode which is particularly important in the event of unexpected conditions. Dexterity, autonomy, foresight and ingenuity are also very important characteristics which make human influence unique and irreplaceable, when compared to robotics or telepresence. Interaction with, and alteration of, experiments will decrease the complexity of the experimental hardware, thereby, decreasing the cost and most probably the weight of the experimental system. Nearly every function to be carried out by the platform becomes enhanced with the presence of humans on board. The commercialization aspects are brighter since the corporate sponsors know there is a higher chance of success for the experiments to be completed without failure. The Space Application Board has put together a brief section concerning the role of man in space. This is duplicated in figure 1.

A long term testing site or proving ground for science and engineering developments will be established. The GSH has many possible long term missions including: a base for asteroid mining

THE ROLE OF MAN

The Panel can identify a number of roles for a human in space which may be grouped under the following headings: transient-phenomena identification; data-quality assurance; data processing, compression, and storage; experimentation; and repair, maintenance, and servicing. These roles are described in ensuing paragraphs.

Transient-Phenomena Identification

Transient phenomena or episodic events such as hurricanes, volcanic activity, tornadoes, and floods cannot be predetermined as to precise time of occurrence or location, but a human in space could tell when a phenomenon was in progress or imminent, and could select the appropriate mode of data collection. For some events, the alerting of ground-based agencies could provide for better emergency planning. Direct notification of public communications channels as to the width, path, and direction of a natural disaster may help save lives and protect property.

Data-Quality Assurance

Man could be used to monitor the quality of data collected in a space station. A human in space will be nearer to the sensors and therefore could more readily identify the source of any sensing or measuring problem and make the necessary correction. He could also control the instruments by changing bandwidth, response intensity, and fidelity range. Further and more rapid improvement of data quality could be achieved if a person is observing the instruments as they perform.

Data Processing, Compression, and Storage

As previously noted, a trained human operator in a space station could accept or reject data, decide to apply data-compression techniques, and decide whether to store data onboard or transmit it to the ground. All of these functions could result in a substantial reduction of the enormous volume of data that would otherwise be transmitted to earth and would have to be processed before its utility could be evaluated. The savings in data relay demands and data processing costs could be significant.

Repair and Servicing

The in-flight repair of Skylab not only saved the mission from a disaster, but also enabled the astronauts to complete most of the experimental objectives. Many of the solutions for failures or problems in a space station would likely be determined on the ground, but a human in space would be needed to make the actual repairs. When one considers the variety of instruments and sensors that could be used for remote sensing from space, the value of a human for in-situ repair and servicing becomes apparent.

Figure 1.

camps; a manufacturing plant for large space structures using lunar material or asteroids; a reprocessing plant for satellites and related debris; a staging base for planetary or deep space missions; and a site for space travelers to reacclimate to gravity after extended missions in microgravity. The station can also be a testing site for: a regenerative life support system or a controlled ecological life support system (CELSS); long term space habitaiton; radiation effects on plants and animals and materials in space.

Health considerations must now be made for the humans aboard the GSH. Unlike the shuttle where people only encounter the microgravity space environment for short periods of time, approximately a week, stays onboard the space station will be nearly six months. Repeat missions could easily result in the equivalent of years of microgravity exposure. By examining data from past long term missions of American astronauts, as well as the Russian cosmonauts, it can be shown that health deteriorates rapidly unless special precautions are taken. More than 50% of all people entering the microgravity environment suffer from an acute malady called Space Adaptation Syndrome. Symptoms are noted by nausea, disorientation, vertigo and in extreme cases vomiting. There is also a high loss of bone calcium observed in microgravity. The high loss of bone calcium is coupled with an increase in calcium in other parts of the body. The unfamiliar environment also causes: heart and skeletal muscle degradation, a redistribution and loss of body fluids resulting in kidney malfunction; loss of muscle tone; and weakened cardiovascular and skeletal systems. (Rose, 1986, Appendix A)

Many acute effects, as well as the potential irreversible physiological changes caused by the microgravity environment necessitate either a rigorous exercise routine, of three to four hours per day, or the incorporation of an artificial gravity. The productivity of the crew is greatly increased by the artificial gravity environment which is an immediate and ongoing benefit of the rotating station. It is estimated that in a microgravity enviroment 30% of all waking hours are spent on maintenance exercise, 25% are lost to human coordination problems and equipment handling problems, and an additional 5% is wasted due to the lack of comfortable accommodations. (Gardener, 1986, Appendix A) Thus, within the artificial gravity environment of GSH, a total of 60% of all waking hours, 17,520 man-hours per six month mission for a ten man crew, can be saved. As the station is rotating, an artificial gravity environment of 0.8 g's at the floor of the station will be induced by rotating the station at a rate of 5 rpm. In this manner it is believed that all of the effects of the microgravity environment will be virtually eliminated.

The critical path for the justification of a multi-use platform to a manned space habitation has been developed. Presently, the U.S. has a high technological advantage which should not be erroded by the lack of foresight. Industry spent $10 million in 1981, $100 million in 1983, and will spend a projected $65 billion annually by the year 2000. However, this preliminary design also calls for a political justification as the LEO station has. Because the station is manned, it is more visible in terms of the general public's attention. The importance of this issue must not be over looked as political ramifications will certainly increase as future space ventures and business investment also increase. Future development of the space program must progress to challange American technology and leadership, as other countries will also be competitive in space activities.

To add the GSH project between the LEO space station, and the lunar and Mars bases . As constuction of the LEO space station is currently under way, the design and development of the GSH project is certainly the next logical step towards future deep space missions to Mars and beyond.

The Geosynchronous Environment

An understanding of the type of environment that exists in geosynchronous earth orbit is tantamount to designing structures that will function and support human presence at this location. This position above earth, 35786 km, locates the space station in radiation and micrometeoroid environments.

The radiation environment at geosynchronous orbit is derived from three sources; the trapped, solar and cosmic radiations (see fig. 2). At this orbit, the station will encounter the outer fringes of the Van Allen radiation belts. A specific problem that can develop from the trapped particles in these belts is spacecraft charging. When passing through these belts, the charged particles may tend to accumulate on the leading edge or side of the spacecraft. When this occurs, the accumulated charge may arc, or short across the vehicle resulting in severe health consequences to the crew and damage to onboard systems, possibly even disabling the entire ship. This problem can be alleviated if the spacecraft and all external surfaces and equipment are grounded.

The trapped radiation of the Van Allen belts is composed of particles held within the field lines of the magnetosphere. These belts include both negatively and positively charged particles. The energy levels of these particles range from 0.1 to 3 MeV and the flux levels range from 10^2 to 10^8 particles/cm^2-sec.

The solar radiation environment also consists of negatively and positively charged particles. This radiation, also known as the solar wind, is always present and remains relatively constant except for periods of increased solar activity called solar flares. It is this radiation that poses the greatest threat to astronauts in geosynchronous orbit because of its combination of high energy levels, from 1 to 600 MeV, and high flux rates, from 10^5 to 10^{10} particles/cm^2-sec.

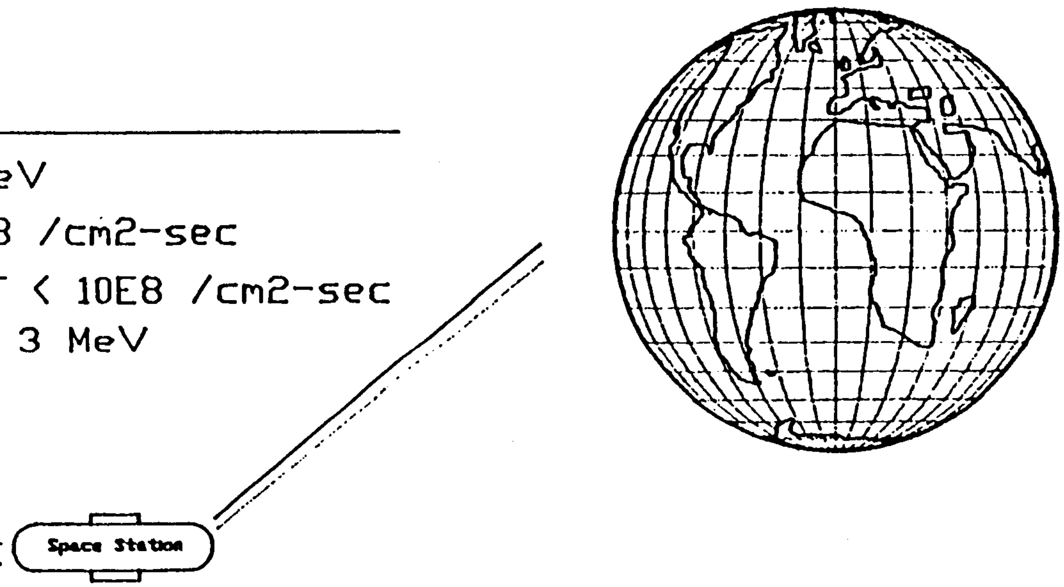
The galactic radiation is that radiation which emanates from outside the solar system. The flux levels are very low relative to the other types previously presented, on the order of five protons/cm^2-sec. The energy levels of these particles, however, range from 10 to 10^{13} MeV. The dose levels received from this form of radiation, however, are not expected to exceed any standards for radiation exposure limits established by NASA (Canon & Madler, 1986, Appendix A).

Radiation is described in terms of dosage. The rad, or radiation absorbed dose, is one of the more common terms associated with radiation terminology. It is equivalent to the amount of radiation of any kind that deposits 100 ergs per gram of material . It is also equal to an electron with an energy of 10^9 MeV. When discussing the effects of radiation upon humans it is more appropriate to use the term REM (or Roentgen Equivalent Man). This is because of the varying levels of damage that different radiations cause in human tissue (i.e. an x-ray of an 200 KeV

THE RADIATION ENVIRONMENT OF GEOSYNCHRONOUS ORBIT

TRAPPED RADIATION

PROTONS	E < 1 MeV
	F < 10E8 /cm2-sec
ELECTRONS	10E2 < F < 10E8 /cm2-sec
	.1 < E < 3 MeV



GALACTIC RADIATION

F = 5 protons/cm2-sec

10 < E < 10E13 MeV

SOLAR RADIATION

10E5 < F < 10E10 protons/cm2-flare

1 < E < 600 MeV (ave =100)

Figure 2

energy level will cause more damage than a 4,000 KeV gamma ray) and is defined as the relative biological effectiveness ; RBE. Some suggested exposure limits and constraints are presented in Table 1. Radiation exposure limits that exceed these limits increase the loss of bone marrow, the probability of skin cancer and the likelihood of genetic mutations (Canon & Madler, 1986, Appendix A, p. 4 & 18).

Acute radiation, that received within a short period of time (usually a week), can be fatal if the dosage levels are significant. For example, an acute exposure of 200-350 rads has a 20% chance of causing death. Survivors of this exposure would be convalescent for approximately three months. Other, less severe effects of acute radiation doses include radiation sickness (e.g. fever, hemorrhage, diarrhea, and emaciation), vomiting and nausea. Table 2 relates the danger presented by the types of radiation present in geosynchronous orbit to specific dose levels. For example, the dosage from trapped radiation is expected to be around 4000 rads/year and would be fatal if improperly shielded against.

As mentioned previously, there is a hazard to crews and structures in geosynchronous orbit that is created by micrometeoroids (particles of less than one millimeter in radius and densities between 0.16 and 4.0 g/cm^3). This hazard, in the form of station puncturing and materials degradation, derives from the velocities and flux rates with which these solid extraterrestrial particles possess.

They range from between ten to eighty kilometers/sec in velocity. This lower limit is due to the gravitational potential of the earth and the upper limit is due to earth's orbit velocity about the sun plus the parabolic velocity, at one astronomical unit, in the solar system.

Direct flux measurements in the vicinity of the earth from sensors on space probes have shown relationships exist between particle mass and frequency of impact upon objects in this environment. These relationships are:

$$\text{Log } N_t = -14.37 - 1.213 \text{ Log } M \quad \text{when } 10^{-6} < M < 1$$

$$\text{Log } N_t = -14.339 - 1.584 \text{ Log } M - 0.063 (\text{Log } M)^2 \quad \text{when } 10^{-12} < M < 10^{-6}$$

where N_t is the number of impacts by particles of mass greater than or equal to M grams per square meter per second. For example, the flux rate for micrometeoroids of mass of 10^{-5} grams have a flux of approximately 5×10^{-9} particles/m^2-sec (see fig. 3).

Shielding

As has been shown, the radiation and micrometeoroid environments in geosynchronous orbit will pose a significant threat to the inhabitants and structure of the proposed space habitat. The sheilding required for micrometeoroid protection also provides additional protection against radiation. Plasma shielding used in conjunction with this shielding will be sufficient protection against the radiation hazards present on orbit.

The proposed method for furnishing micrometeoroid protection will be bumper shielding.

Table 1: Suggested Exposure Limits and Constraints (REMS)

Constraints	Bone Marrow	Skin	Testes
30 Day Maximum	25	75	13
Quarterly Maximum	35	105	16
Yearly Maximum	75	225	36

COMPARISON OF EXPOSURES	
Daily Life	60-200 mREMS/year
Nuclear Power	400 mREMS/year

Table 2: The Danger

Acute Radiation Effects

Dose (rads)	Deaths
200-350	20%
350-500	50%
>500	100%

Expected Radiation at Geosynchronous Orbit

Type	Dose (rads)
Galactic	<4/year
Trapped	4000/year
Solar	10-1000/flare

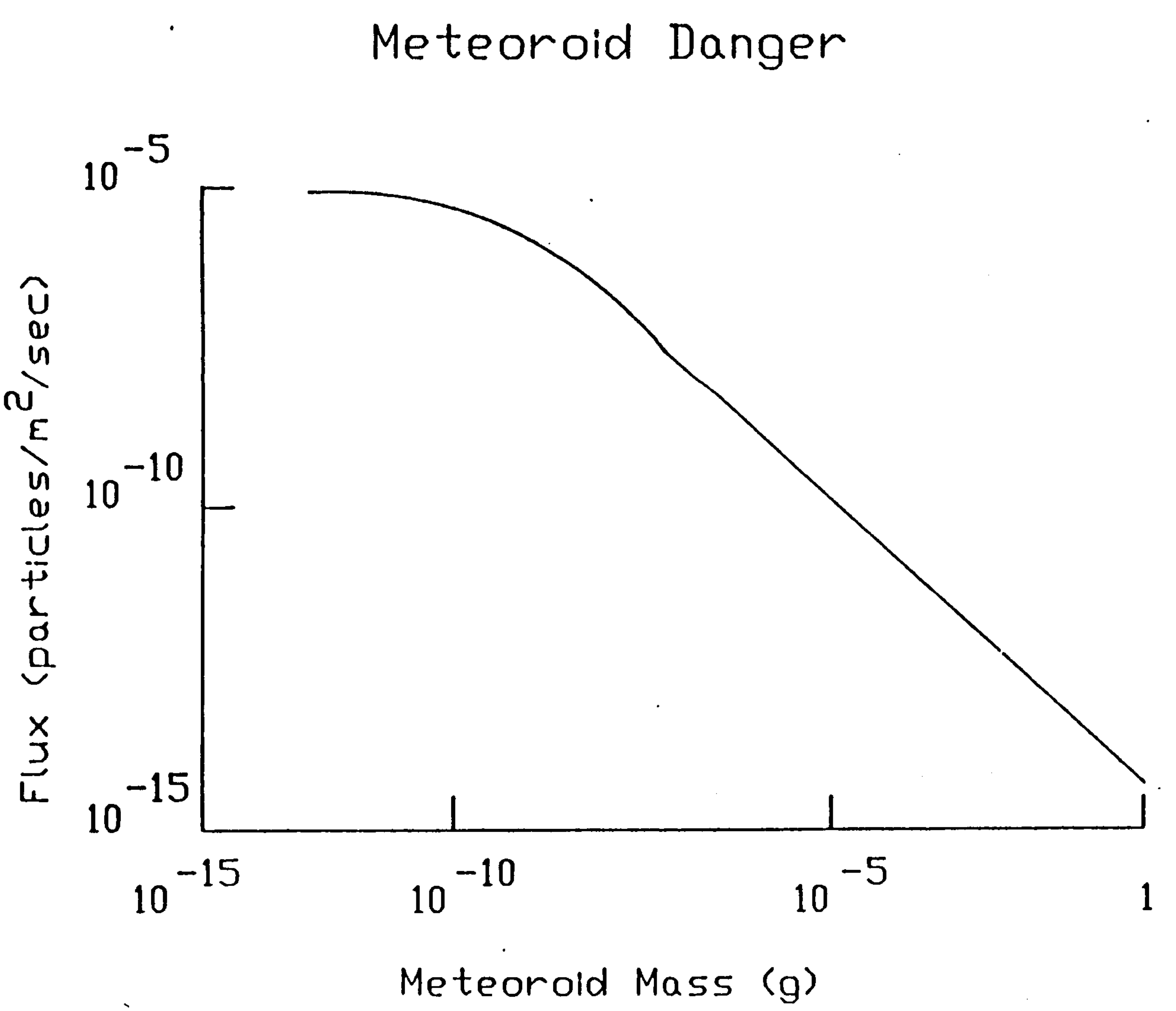

Meteoroid Danger
10^{-5}
10^{-10}
10^{-15}
Flux (particles/m^2/sec)
10^{-15}
10^{-10}
10^{-5}
1
Meteoroid Mass (g)

Figure 3.

Double-wall construction will provide this shielding. A meteoroid impacting the first surface, made of one millimeter thick Kevlar, becomes vaporized as it penetrates this shield. The vaporized cloud created increases in size as it travels between the shields until it impacts with the second wall. The separation between these walls will be 200 mm. This insures the cloud will have spread out over a wider area upon impact (than closer spaced walls), thus lowering the impact force so that they do not have sufficient force to penetrate the wall. This double-wall structure will also minimize heat loss to space and heat transfer to the plasma shielding.

The plasma shielding is a hybrid of electrostatic and magnetic shielding. The concept of the shielding is to charge the station to an electrostatic potential between 40 and 60 MeV. This potential repels positively charged particles with energies less than the charged station. Four superconductors, arranged in the form of two sets of tori, create magnetic field lines about the station. The negatively charged particles that threaten the inhabitants of the modules will be captured by the magnetic field lines and held as a plasma cloud (see fig. 4).

The plasma shielding, when in operation (i.e. during solar flare activity), and bulk provided by the modules will shield the station as effectively as 10 g/cm^2 of material. The plasma shielding reduces the requirement for the skin and equipment thickness to be only 2-4 g/cm^2. Weight savings of approximately 95-98% are realized over conventional and bulk shielding. The power requirements for maintaining the plasma shielding is not expected to be greater that 50 kilowatts when in use ("A Geosynchronous Space Station: Year 2005", 1985, Appendix C).

Structure

The overall structure of the space station is in the shape of a toroidal framework with a radius of 30 meters (see fig. 5). This framework was derived from two main design criteria 1) the use of plasma shielding and 2) the stability requirements necessary for a spinning station. As previously mentioned, the station is a torus shape in order to implement the plasma shielding as a means of radiation protection. For a spinning station to be stable it is necessary that it be symmetric. Symmetry also insures the moment of inertia about the central axis, the axis through the center of the torus and perpendicular to its plane of rotation, will have the largest value. A preliminary investigation into the moments of inertia for the station verify that the station will tend to rotate about its central axis. The moment of inertia about the central axis as compared to the other two moments of inertia, which lie in the plane of the torus, is approximately twice as large (see fig. 6). In addition, a simplified finite element analysis has shown the natural resonant frequencies of the station to be between 100 and 1,000 Hz. This approach modeled the station as a five point mass system with two modules each representing a point mass and the central hub representing the fifth.

GSH consists of eight, interconnected habitation modules, of which four are supported by tethers. It is possible to maintain a shirt-sleeve environment throughout the station due to this interconnectivity. Every other module is connected to a torus access tube which joins with the central hub. This central hub is composed of storage, repair (i.e. satellite and equipment) and docking facilities. A power receiving and communications antenna has been attached to the storage

Plasma Shielding (Cross Section View)

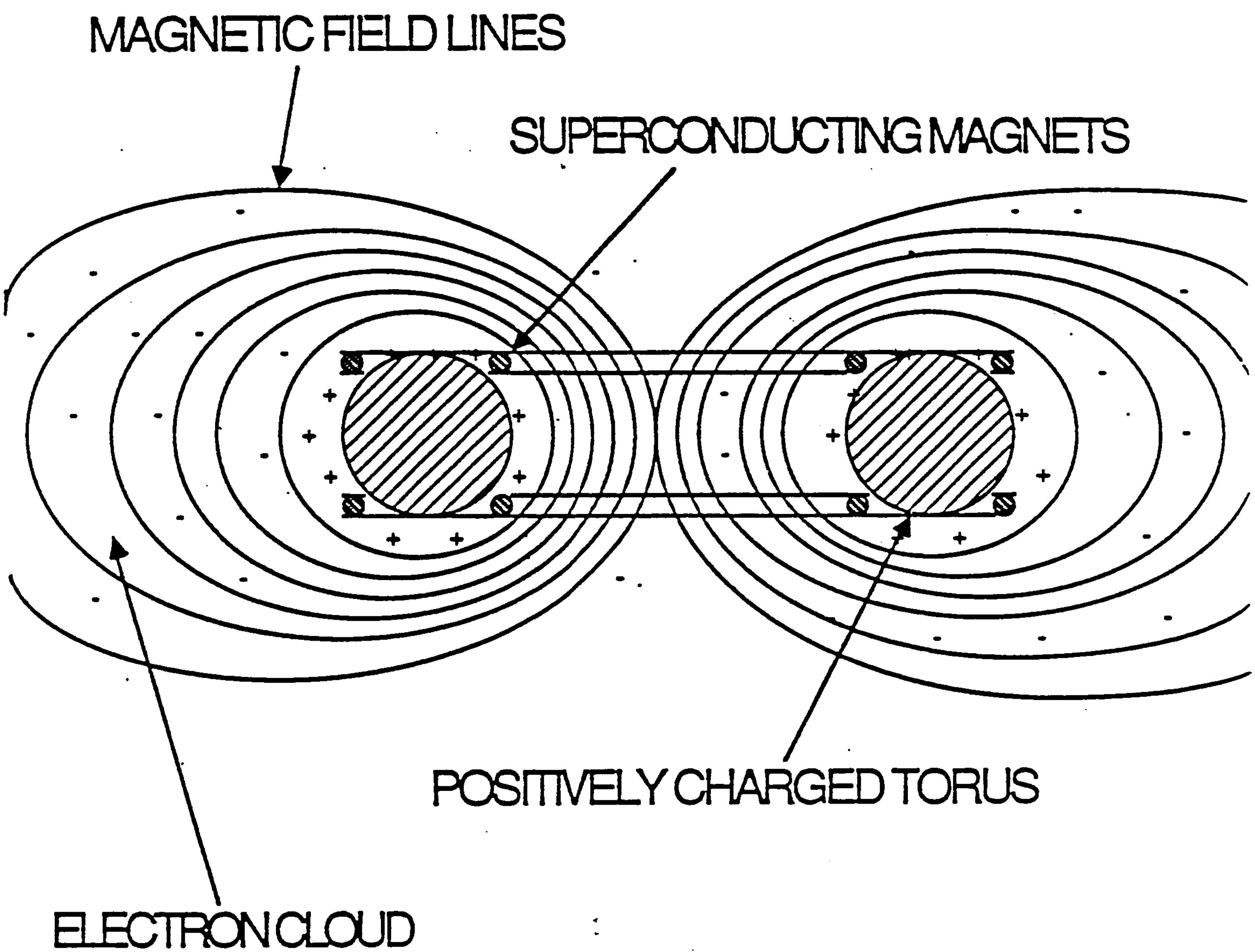


Figure 4.

Geosynchronous Space Habitat

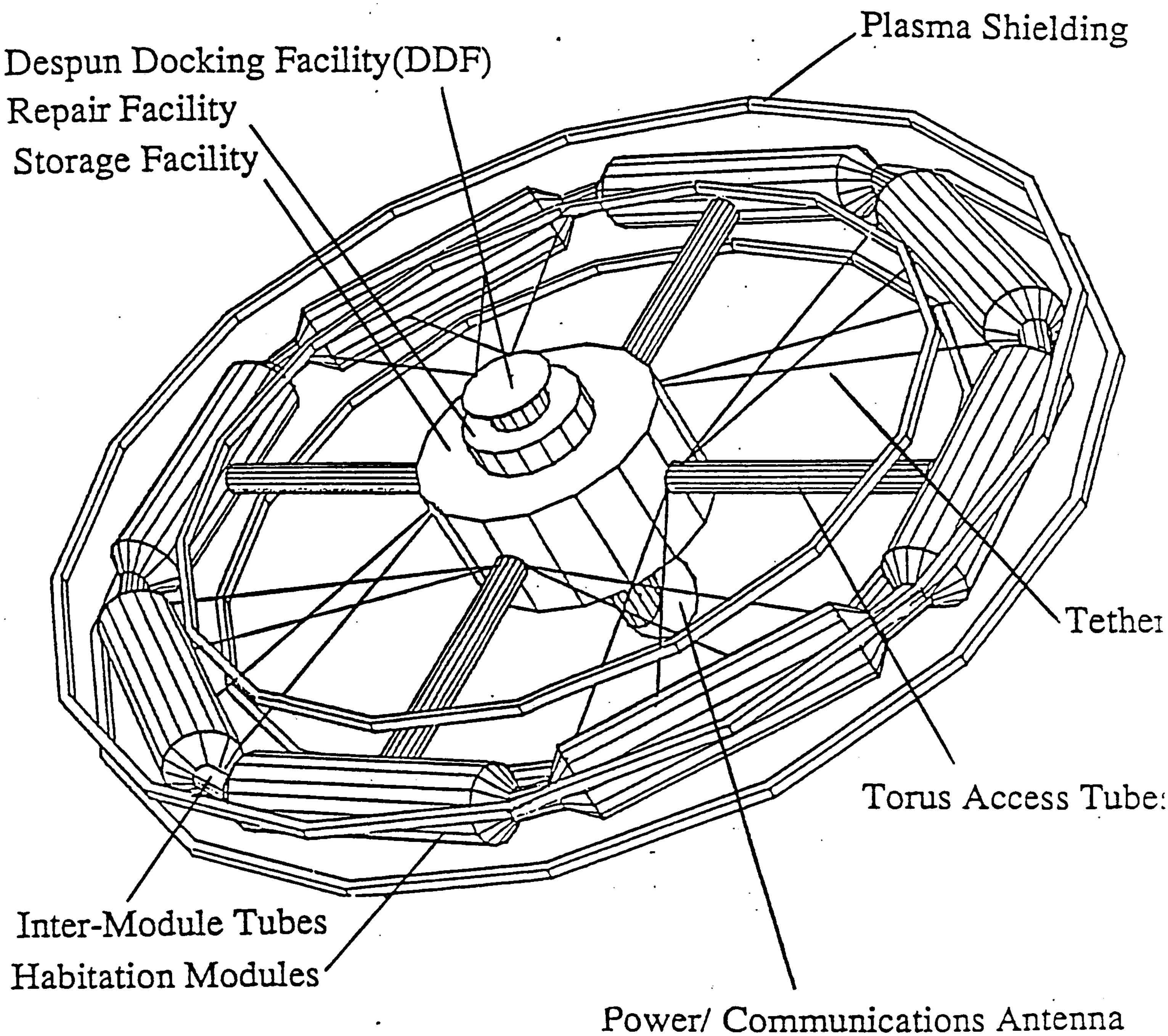


Figure 5.

Moments Of Inertia*

Moment of Inertia Through Central Axis (I_{zz})

Habitation Modules-

$d = 27.75$
$h = 18$
$r = 2.25$
$m = 10,460$/module

$I_{zz} = m/12(6r^2+h^2) + md^2 = 8,363,750$/module

Torus Access Tubes-

Elevator System	Ladder System
$d = 16.75$	$d = 16.75$
$h = 17.5$	$h = 17.5$
$r = 1.0$	$r = 1.0$
$m = 5500$/system	$m = 1500$/system

$I_{zze} = m/12(6r^2+h^2) + md^2 = 1,686,210$/tube
$I_{zzl} = m/12(6r^2+h^2) + md^2 = 459,375$/tube

Storage Facility-

$r = 8$
$m = 5500$

$I_{zz} = mr^2 = 352,000$

Repair Facility-

$r = 4$
$m = 1500$

$I_{zz} = mr^2 = 16,320$

DDF-

$r = 2.25$
$m = 600$

$I_{zz} = mr^2 = 3,040$

Total I_{zz} = 71,573,530 kg-m^2

Moments of Inertia about Access Tube Axes (I_{xx} and I_{yy})

I_{xx} corresponds to the axis through tubes with ladder system
I_{yy} corresponds to the axis through tubes with elevator system

Habitation Modules-

$d_1 = 27.75$
$d_2 = 19.62$
$h = 18$
$r = 2.25$
$m = 10,460$/module

$$I_{xx} = I_{yy} = 2(m/12(6r^2+h^2)) + 2(mr^2+md_1^2) + 4(0.5(m/12(6r^2+h^2) + mr^2) + md_2^2) = 33,663,190 \text{ total}$$

Torus Access Tubes-

Elevator System	Ladder System
$d = 16.75$	$d = 16.75$
$h = 17.5$	$h = 17.5$

Figure 6.

Moments Of Inertia (cont.)*

$r = 1.0$
$m_e = 5500$/system

$r = 1.0$
$m_l = 1500$/system

$I_{xx} = 2(m_l r^2) + 2(m_e/12(6r^2+h^2) + m_e d^2) = 3{,}375{,}420$
$I_{yy} = 2(m_e r^2) + 2(m_l/12(6r^2+h^2) + m_l d^2) = 930{,}750$

Storage Facility-

$r = 8$
$h = 8$
$m = 5500$

$I_{xx} = I_{yy} = m/12(6r^2+h^2) = 205{,}330$

Repair Facility-

$r = 4$
$h = 3$
$m = 1020$

$I_{xx} = I_{yy} = m/12(6r^2+h^2) = 8{,}930$

DDF-

$r = 2.25$
$h = 3$
$m = 600$

$I_{xx} = I_{yy} = m/12(6r^2+h^2) = 1{,}970$

Total $I_{xx} = 37{,}254{,}840$ kg-m^2
Total $I_{yy} = 34{,}810{,}170$ kg-m^2

* All dimensions are presented in meters and all masses in kilograms

d= distance of objects centroid from central axis
d_1= distance of modules (connected to torus access tubes) centroid from central axis
d_2= distance of modules (with tethers) centroid from central axis
h= length of object
r= radius of object
m= mass of object
m_e= mass of access tube with elevator system
m_l= mass of access tube with ladder system

Figure 6.

facility to pick up the power generated from the solar panels which are located approximately 1.2 kilometers from the station.

Overall dimensions and volumes of the individual station components are presented in Table 3. The masses shown represent approximate total component masses. From these figures the station has been estimated to have a mass of approximately 104,810 kilograms.

Currently, the dimensions of the habitation modules are sized as the maximum dimensions allowable within the Shuttle Transportation Systems (STS) cargo bay (4.5x18 meters). The mass of an individual module is approximately 6,840 kilograms and includes the masses of robotics, power, and tether hardware. The exception is a shielded module which has an extra 4400 kilograms of mass for safety during heavy solar activity. The mass required for life support hardware, approximately 18,150 kilograms, will be distributed so that it compensates for this heavier module. The modules will contain working areas, living areas, robotics/control centers, CELSS, medical/emergency facilities, environmental control and general storage. The specific module assignments that have been proposed are shown in fig.7.

Movement from one unit to the next is accomplished using the inter-module tubes. These eight tubes, with flexible joints, comprise the connections between the modules. The flexible joints of these tubes will aid in dampening disturbances that may occur in the rotating space station and will also decrease vibrational transfer between modules.

The torus access tubes provide four approach routes for astronauts entering the habitation modules from the storage facility. Two of the shafts will be equipped with elevator systems and the other two will contain ladder systems. The elevator system will be located on the opposite side of the storage facility as its counterpart. This is also true of the access tubes which contain the ladder systems. The ladders will be used as secondary exits, i.e. if the elevators have a failure the astronauts will still have other means of movement from the habitation modules to central modules. The shafts that contain the ladder systems can also be used as a means for distributing masses.

The reasoning for having four tubes attached to the habitation modules is to produce a more stable structure. The structure is similar to a wheel with spokes. With two spokes attached the station would be more flexible in its plane of rotation than with a three spoke system. In order to maintain symmetry and have increased stability a four spoke system was required. This system will increase the stations rigidity within its plane of revolution, i.e. distortion of the structure will be reduced.

Torus access tubes will be structured so that they possess flexible joints at the habitation modules but not at the central hub, thus, they will contribute to some station dampening, i.e. a disturbance located at the central hub would not necessarily effect the torus modules. They will not, however, provide any axial support to the structure due to the tether configuration. This also has the advantage of creating a more fracture proof structure.

The elevator lift system will be used to transport people and equipment to and from the habitation modules. The elevator system must operate in such a manner as to be safe to the crew and station, impart minimum disturbance to the station's angular momentum and have minimal complexity and weight for the initial assembly and maintenance. Each elevator will have a counter

Module Assignments

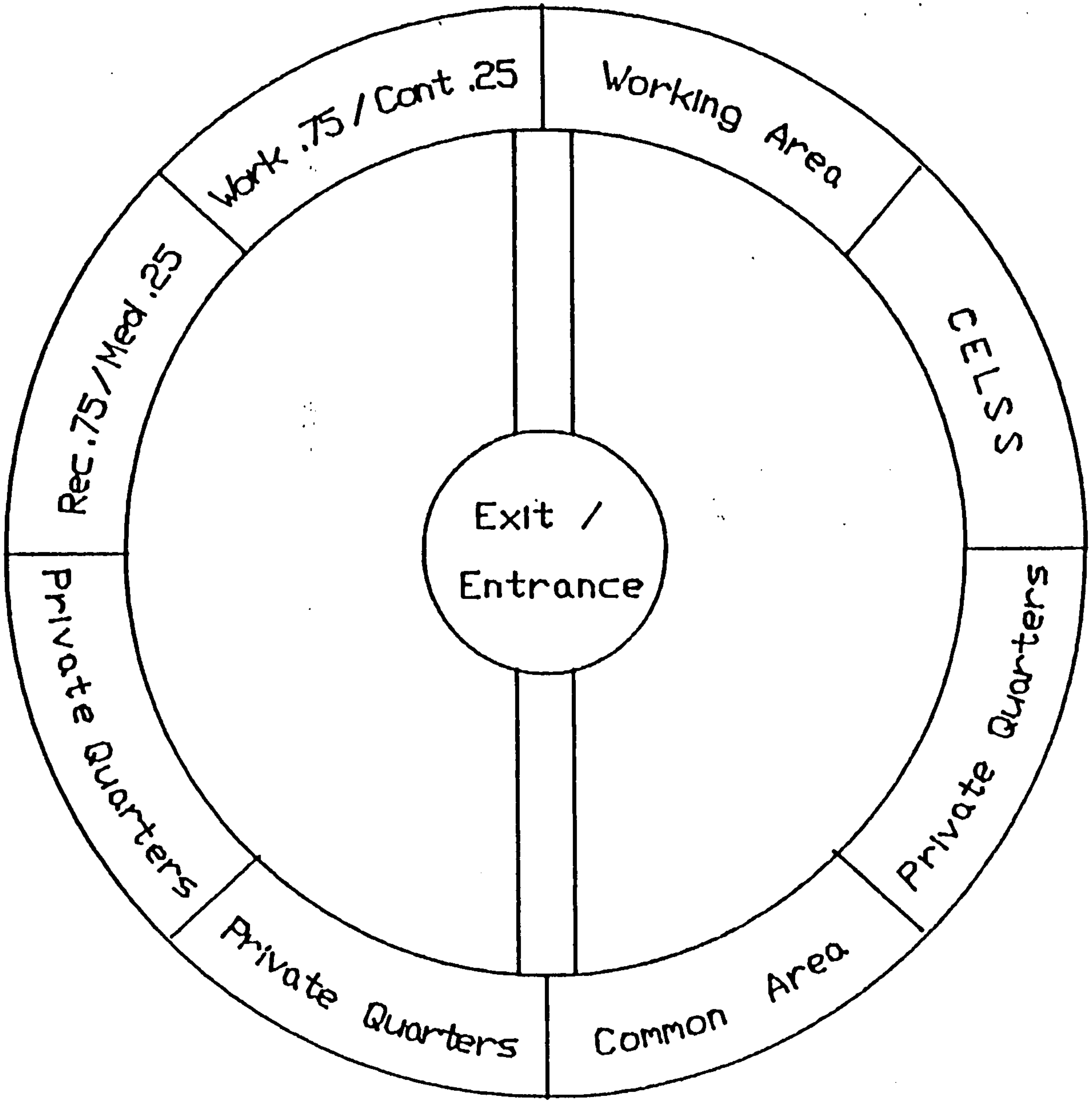


Figure 7.

weight associated with it to minimize disturbances to the stations equilibrium during operation. Disadvantages of the system include the additional stresses on the habitation modules from required buffer springs and counter weights. These elevator systems are approximately 4,000 kilograms in mass and will cost roughly $400,000.

The cylindrical storage facility will provide the station with approximately 1,610 cubic meters of volume. This entire amount, however, will not be available for storage due to elevator system volume requirements at the module and storage interface levels (i.e. elevator pits and overhead spaces) and access clearances within the facility. Upon taking these items into consideration then the storage available for materials and supplies is reduced to 1,170 cubic meters.

The repair facility will house equipment necessary for conducting satellite repair. It is comprised of two concentric cylinders, of which the outer one is rigidly attached to the storage facility. The repair facility, when spinning, has a one-tenth-g environment at its walls. This would not be acceptable for shifting around large and awkward satellites, thus it has the capability for internal despinning so that repair work may be effortlessly conducted in a zero-g environment.. This process of despinning will be accomplished using magnetic bearings.

Connected by a sleeve to the outer shell of the repair facility is the despun docking facility (DDF). The sleeve contains magnetic bearings to allow for spin/despin capability. This allows docking vehicles (e.g. the shuttle) ready access to the interior environment of the station. This facility and the repair facility can be operated independently of each other, allowing either one or both to be despun, depending upon the desired activity. A four section circular supply rack hooked to the DDF will allow materials and to be unloaded from the docked vessel and stored until their use is required by the station. They also allow for the stowage of oversized cargo that will be used outside of the station. Each section is approximately 15.2 m^2 in area.

The last major components constituting the station structure are the tethers. Tethers are two force members, of high thermal stability, incapable of flexure or compression. They do, however, support axial loads. Four tethers will be used to distribute the radial load across the habitation modules which have no torus access tubes attached to them. This will relieve radial stresses that occur in the modules due to the rotation. Both ends of the tether will be attached to reels in order to provide easy adjustment for controlling overall station flexibility. The network designed also allows for some tangential load to be supported by the tethers. It is expected that these tethers, constructed from Kevlar, will have a tensile strength of approximately $9.66x10^8$ N/m^2 and a density of 2,000 kg/m^3. Vapor deposition techniques will be used to coat the Kevlar tethers with an aluminum coating in order to protect them from radiation degradation. This coating will have a negligible effect upon the tether mass.

Table 3: Structure Dimensions, Volumes and Masses

Component	Dimensions/Item Diameter (m)	Length or Height (m)	Volume/Item (m^3)	Mass (kg)
Habitation Modules (7)*	4.5	18	286.3	66030
Shielded Module (1)	4.5	18	286.3	11240
Inter-module Tubes (8)	2	4.4	13.8	3200
Torus Access Tubes				
Elevator Systems (2)	2	17.5	55.0	11000
Ladder Systems (2)	2	17.5	55.0	3000
Storage Facility (1)	16	8	1608.5	5500
Repair Facility (1)	8	3	150.8	1020
Despun Docking Facility (1)	4.5	3	47.7	600
Tethers Lines (16)	.005	29.1	.00057	20
Plasma Shielding (4 rings)	----	----	----	3200
			Total Station Mass	104,810

* - These masses include CELSS, robotics, power and tether hardware

Power

In order to be a viable system, the power system of GSH must meet several design criteria. Most importantly, the power system must generate enough power to operate all the systems necessary for daily operation plus it must provide enough auxilary power capability for any unexpected problems or further mission demands. Based on the power demands of sustaining 20 crew members, CELSS, the plasma shield, scientific experiments, and all other necessary support facilities, the system must generate at least 250 kW of power for the desired operational proficiency. A Geosynchronous Space Station: Year 2005', 1985, Appendix C) Besides generating the required power, the system must also perform reliably, safely, and efficiently.

GSH must be as autonomous as possible, capable of operating independently of any earthbound sources. Therefore, instead of using less expensive microwave power transmitted from the earth, the power of GSH will be generated from two free flying arrays. Using these arrays will also complement the desired design characteristics of efficiency, safety, and reliability. The primary advantage of the spacebourn power generator is reliability. Unlike earth-to-GEO power transmissions which typically lose up to 80% of the transmission intensity, only 2-5% on the average will be lost in a space-to-space situation. Unlike a nuclear power source, the microwave power source is very safe for the crew to be working around. Microwaves will not cause the physiological harm that fission by-product radiation will.

In view of the desired design characteristics, the power generator system will be a series of Cassagranian collectors coupled to multi-band-gap cells. (see fig. 8) This system must generate at least 50 kW of power for maintenance of the life support and shielding systems, and under normal operating conditions, must generate 250 kW . To accomplish this, the sun's energy is concentrated by 45,000, 5mm x 5mm miniature mirrors onto a multi-band-gap cell which is constructed of photovoltaically active materials. These materials are capable of absorbing wavelengths of light from 400nm-2000nm. This system will afford an efficiency of 68% by the year 2000 which is a three-fold increase in present silicon or galium arsenide systems. At full operation, the arrays will produce power at a cost of $30,000/kW. These components will be mounted on a 45 square meter solar array parasol mounted on a co-orbiting, free flying satellite positioned approximately 1.2 km from the station. Energy will be transmitted to a 5m diameter receiving antenna located on the end of the station opposite the docking port. The antenna will be decoupled from the spin of the station so that transmissions can be received despite the position of the station with respect to the power satellite.(see fig.9) The second array will provide 100% redundancy for the power sytem in addition to allowing directional power capabilities without disturbing the normal power consumption of the station.

Obviously, this two array configuration will meet, if not exceed, the desired design characteristics. Despite the cost penalty of this space-based system, it affords the benefits of safety and operational efficiency as well as meeting all of the design objectives.

Waste Heat

An important subsystem related to the power requirements is thermal management, which includes the acquisition, transport, and rejection of waste heat. Controlling the continuous heating, circulation, and cooling needs of the station while maintaining an average temperature of 20 .0-21.5 degrees celsius is a directive of considerable importance. Even though the sun's energy and the power receiving antenna are the only external sources of heat, the total system capacity must be at least 250 kW to be compatible with the power generation system. Therefore, a freon heat pipe circulation system will run throughout the station for thermal control. Waste heat, or heat with too low a quality to be useful will be pumped out of the station through numerous space constructable radiator panels. Using this method, 97% of the waste heat can be diminished. The remaining 3% can can be disposed of through recirculation means. The freon heat pipes will be arranged in a 'honeycomb' pattern. If a leak or breakage occurs, the freon flow can be restricted to other operable pipes while still cooling the same regions of the space station. Each of these panels can easily be removed or installed without breaking the connection of the fluid loop. By using this approach, system reliability is increased, while the damage from potential meteoroid strikes is localized to one small area of the system.

CASSAGRAINIAN CONCENTRATOR ELEMENT

SUBASSEMBLY MOUNTING

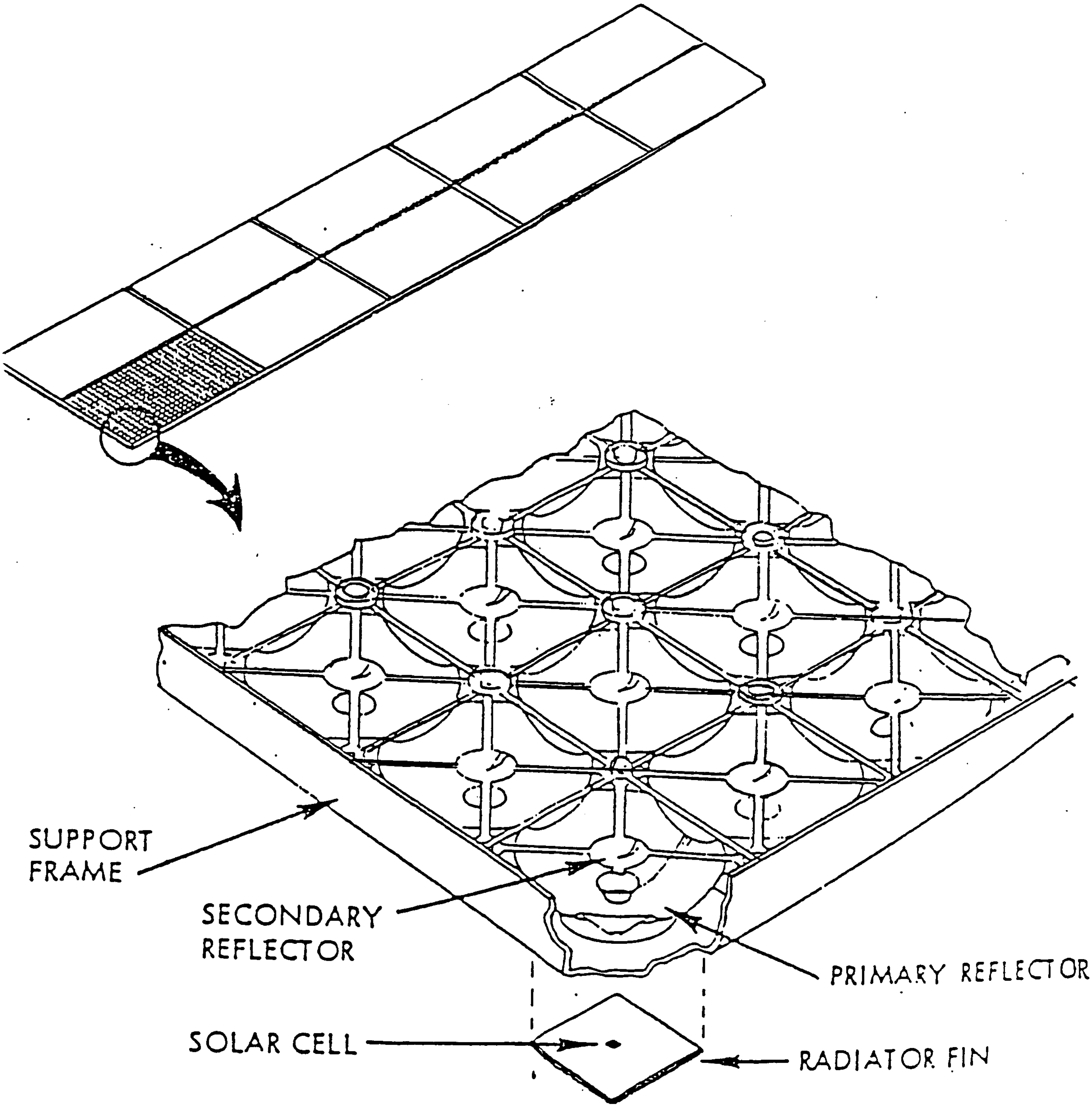
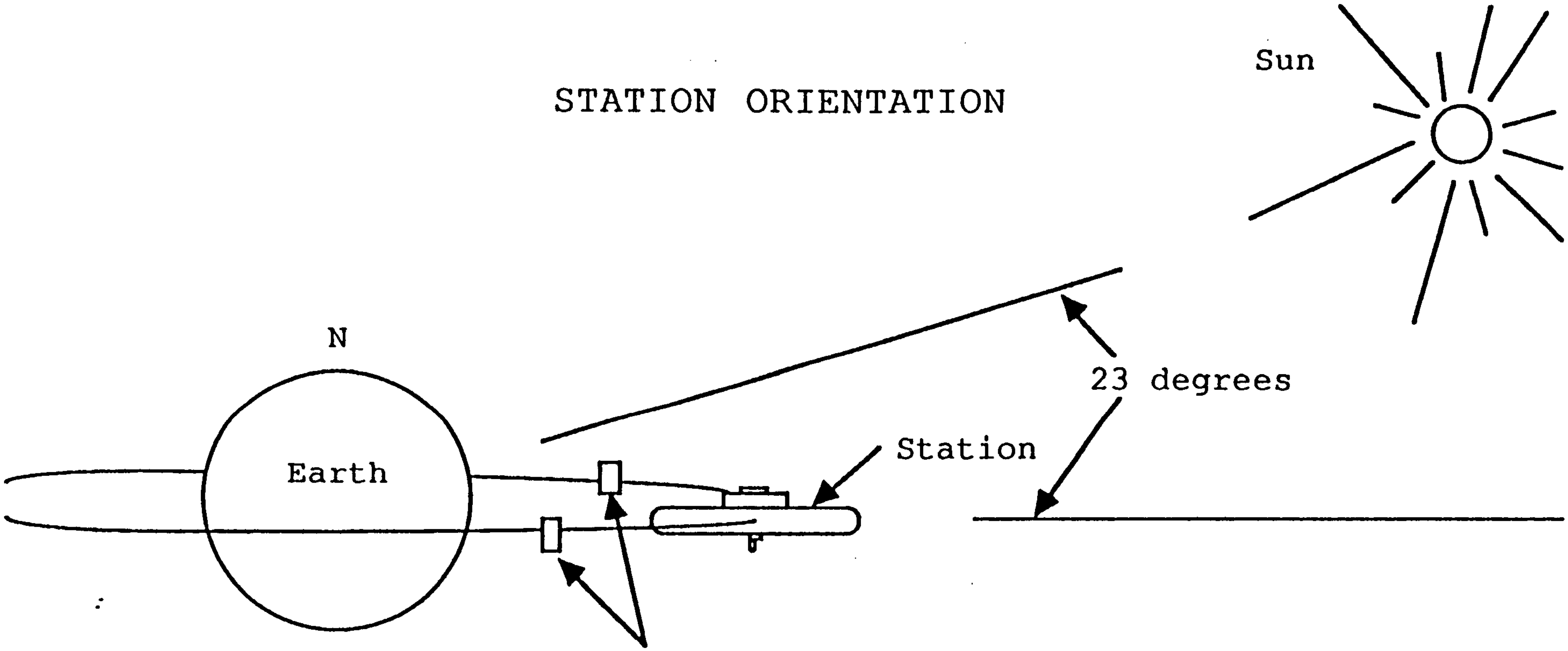


Figure 8.

STATION ORIENTATION



* Not to Scale

Figure 9.

Life Support

Guidelines

The life support system for GSH involves more than the spartan survival methods of many space missions. To optimally utilize the human factor a healthy and comfortable environment must be provided. However, the initial step in defining the life support system is to determine the basic survival guidelines.

GSH is located in geosynchronous orbit. Because of this location, there are several environmental factors that the crew must be protected from. Most notably, there is plasma shielding protecting the humans, other life, and onboard equipment from the radiation danger. A maximum acceptable level of radiation is eighteen rem of a six month period.(Cannon and Madler, 1986, Appendix A) This is considerably higher than those values encountered here on earth; about 20 mrem at sea level in the same period of time. It is believed, however, that the crew can be exposed to these values and not suffer from any debilitating acute or long term changes in physiology.

Maintenance of proper atmospheric content within the station is a second critical duty of the life support system.

partial pressure of Nitrogen	: 110 mmHg
partial pressure of Oxygen	: 400 mmHg
partial pressure of Carbon Dioxide	: 4 mmHg
partial pressure of water vapour	: 9 mmHg (Thompson,1962)

There is a small envelope of acceptability associated with each of these values; these are only representative values. If the atmospheric content is not maintained and monitored very closely, crew discomfort, impairment, and even death can occur. For example, it is optimal for the partial pressure of CO_2 to be less than 5 mmHg, at 10 mmHg discomfort is felt, and at 20 mmHg there is physical impairment. (see fig. 10) There are similar such effects with all of the constituents of the atmosphere.

The crew will also require food, water, and oxygen.
Representative values are as follow.

metabolic oxygen	.91 kg/man-day
drinking water	3.64 kg/man-day
hygiene water	5.45 kg/man-day
food	0.59 kg/man-day

Coupled with this input there is a certain output. It is necessary to know the output as well as the input to the system to fully understand the operational requirements of the life support system of GSH.

EFFECT	PARTIAL PRESSURE mm HG
PHYSIOLOGICAL IMPAIRMENT	> 20
DISCOMFORT ZONE	10 - 20
BORDERLINE	5 - 10
OPTIMUM	< 5

CARBON DIOXIDE EFFECTS(CONTINUOUS EXPOSURE)

Adapted from Establishing A Habitability Index for Space Stations and Planetary Bases
Celentano, Amorelli, Freeman

Figure 10.

carbon dioxide	1.02 kg/man-day
water vapour(exhaled breath, perspiration)	2.50 kg/man-day
waste wash water	5.45 kg/man-day
urine	1.45 kg/man-day
feces	0.16 kg/man-day
metabolic heat	12000 BTU/man-day

CELSS

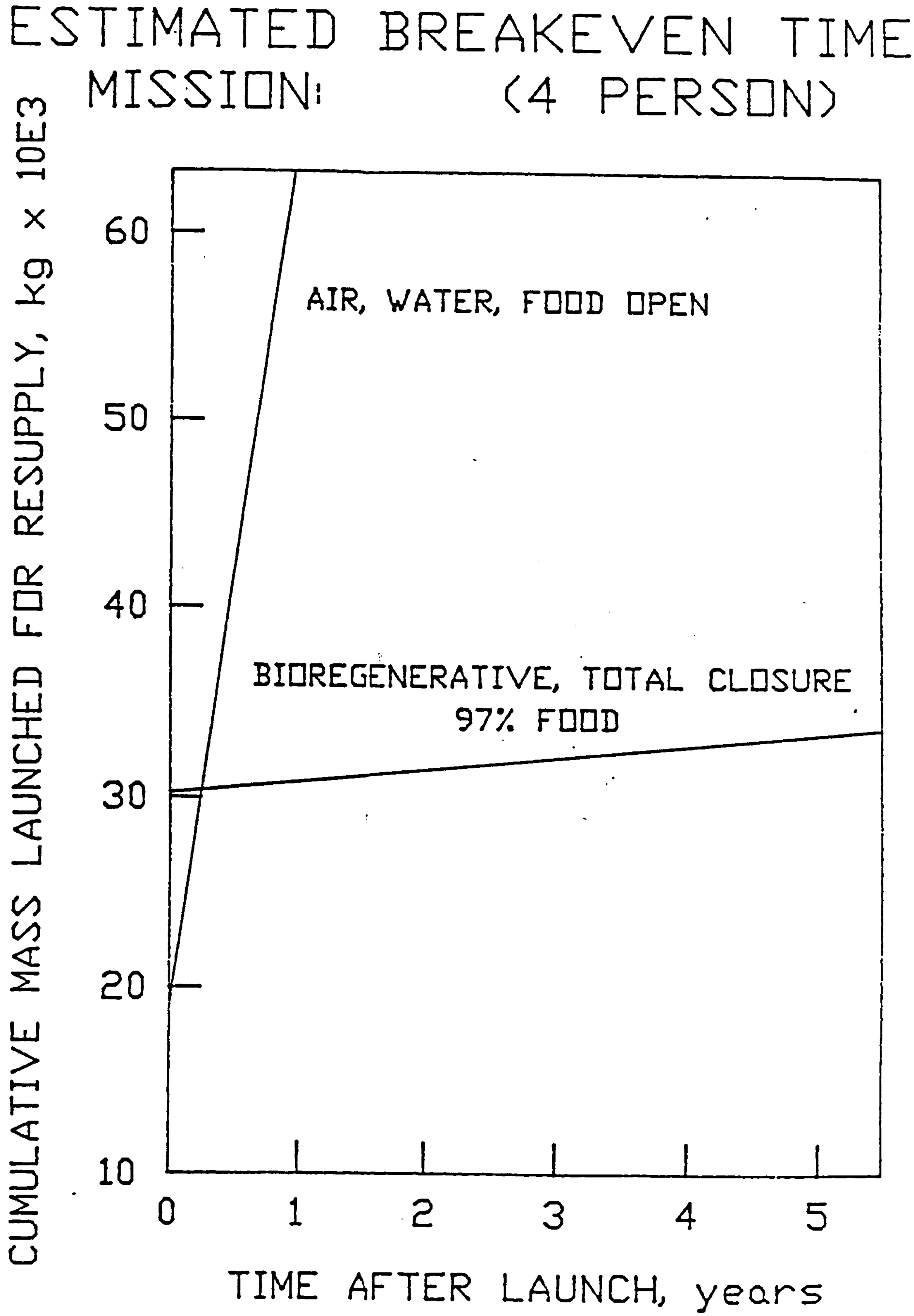
To continuously resupply the space station with supplies to maintain the life onboard is a costly endeavor. The minimum cost to transfer a kilogram of supplies to geosynchronous orbit is about $28,600 dollars. For a ten man crew, approximately 7700 kg of food and water would need to be supplied every six months. This results is a net cost of $220,000,000 dollars every six months for only food and water supply for the crew. A closed ecological life support system, a CELSS, is therefore included in the life support system. The CELSS is a bioregenerative system that will supply food for the crew, will recycle oxygen, water, and wastes , and will maintain its own life cycle. The conventional resupply method is initially less expensive as it does not require the equipment for processing, storage, transfer, and maintenance necessary for CELSS. However, longterm, the CELSS is considerably less expensive. A comparison of the open and a 97% closed food system indicates that the necessary mass supply is equal, for the two systems, at about three months for a four person crew. After this time the open system is considerably more costly.(see fig. 11) For a crew of twelve, an estimated $455 million will be saved over a fifteen year period by using a 97% food closure system instead of resupply. (Gustan et al., see fig. 12) This does not include the cost saved in recycling water and air through the system onboard. An open system is not feasible because of the extreme cost for the duration of missions aboard GSH.

The CELSS consists of lower plants, higher plants, aquaculture, and on a second level the crew, and on a third level all of the necessary support equipment. There will be lower and higher plants as well as aquaculture in the system. The algae will supply all of the oxygen required for the crew and 40% of the food requirements. The higher plants will supply 40% of the food supply, and the aquaculture will provide the remaining 20% of the food requirements. The minimal necessary volumes, masses, and energy for the CELSS components are as indicated:

	volume	mass	power
higher plants	35 m^3	6,000 kg	150 W
algae/aquatic animals	42 m^3	42,000 kg	16 kW

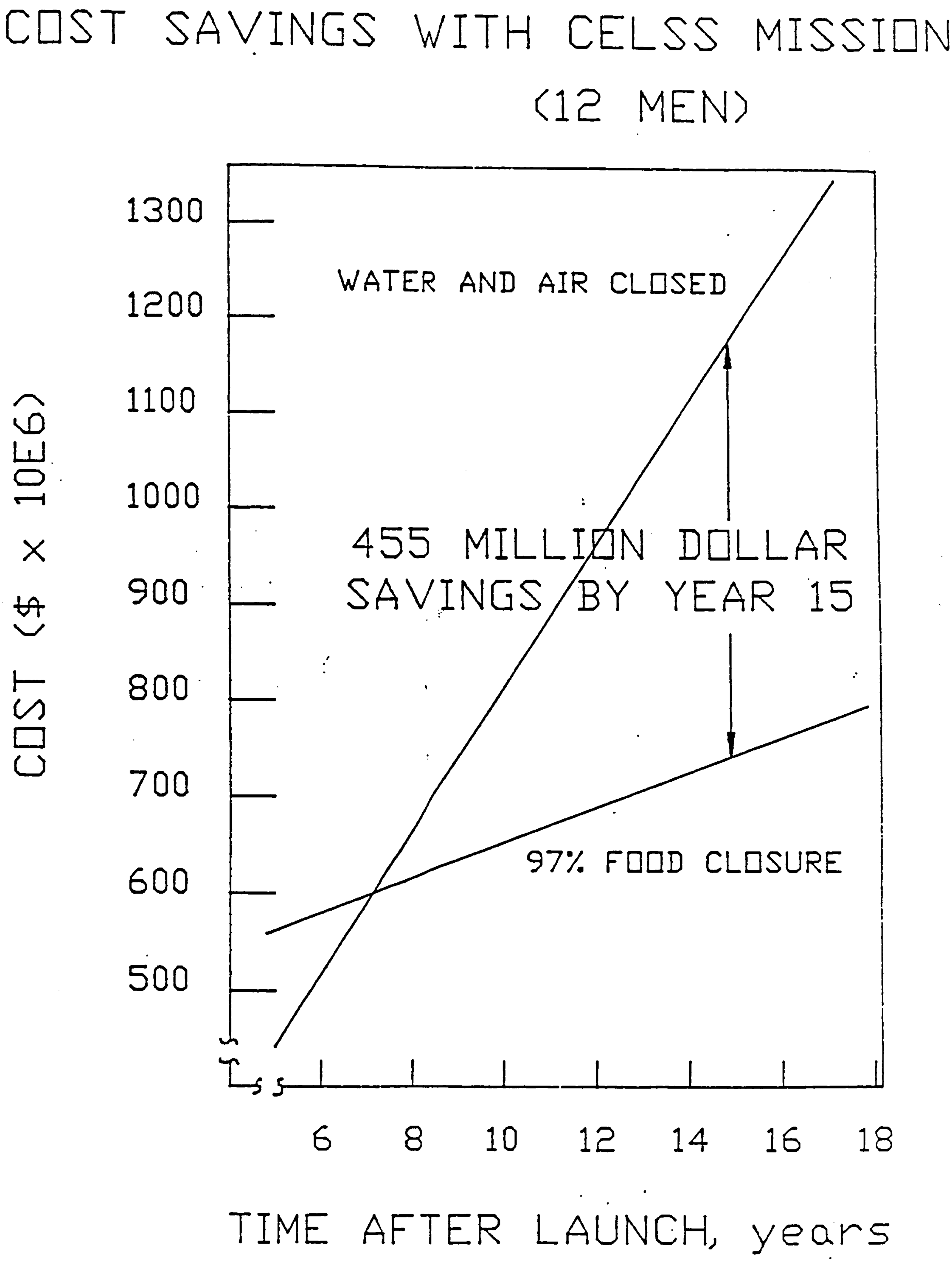
These volumes, providing 100% of the food and oxygen for a ten man crew will fill only 27% of a single module of the station.

The lower plants chosen are microrganisms; blue-green algae, yeast, bacteria, and fungus.



Adapted from: MacElroy et al., Evolution of CELSS for Lunar Bases, in "Lunar Bases and Space Activites of the 21st Century", W.W. Mendell,

Figure 11.



Adapted from: Gustan et al; Controlled Ecological Life Support System: Transportation Analysis, NASA CR 166420

Figure 12.

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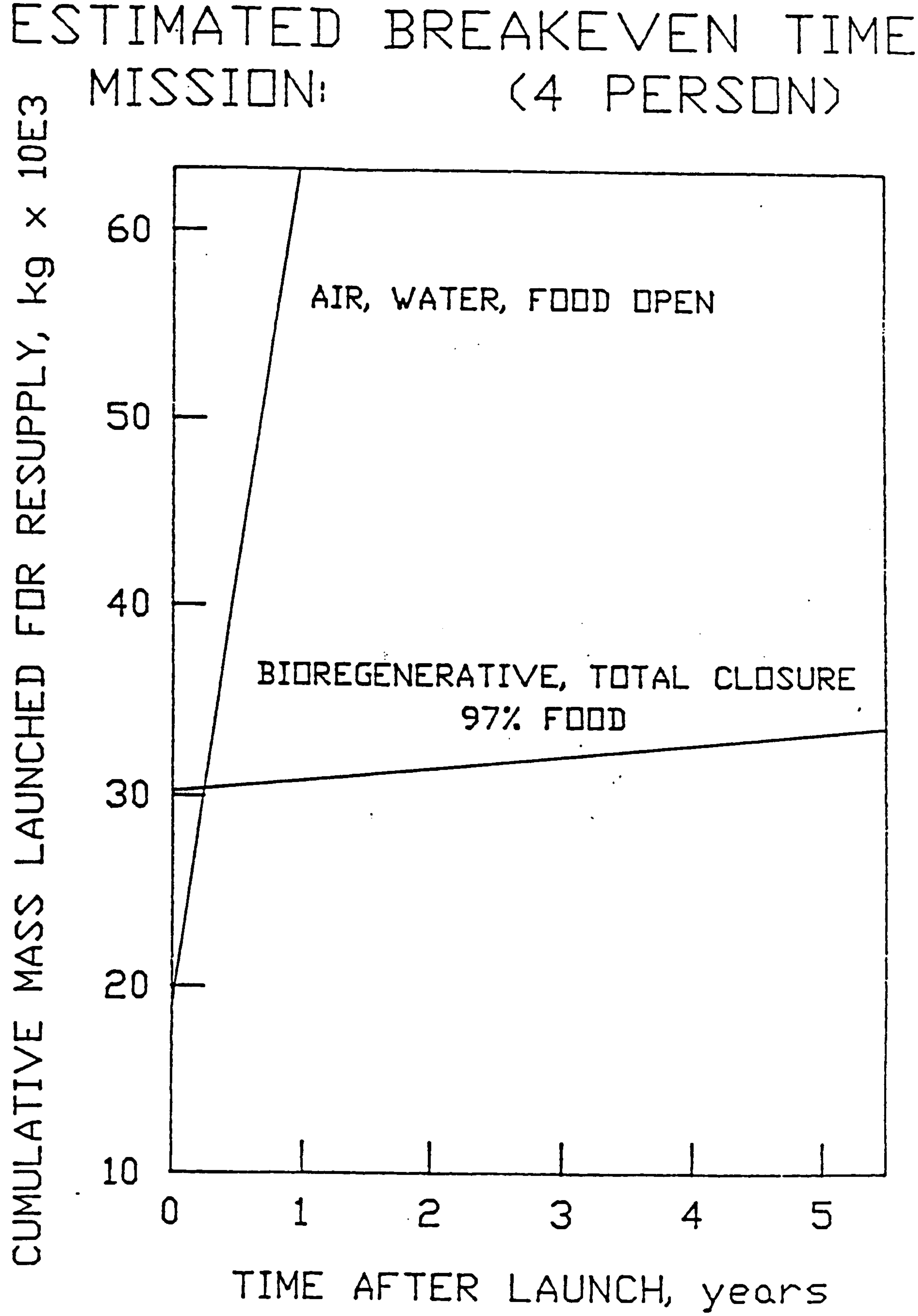
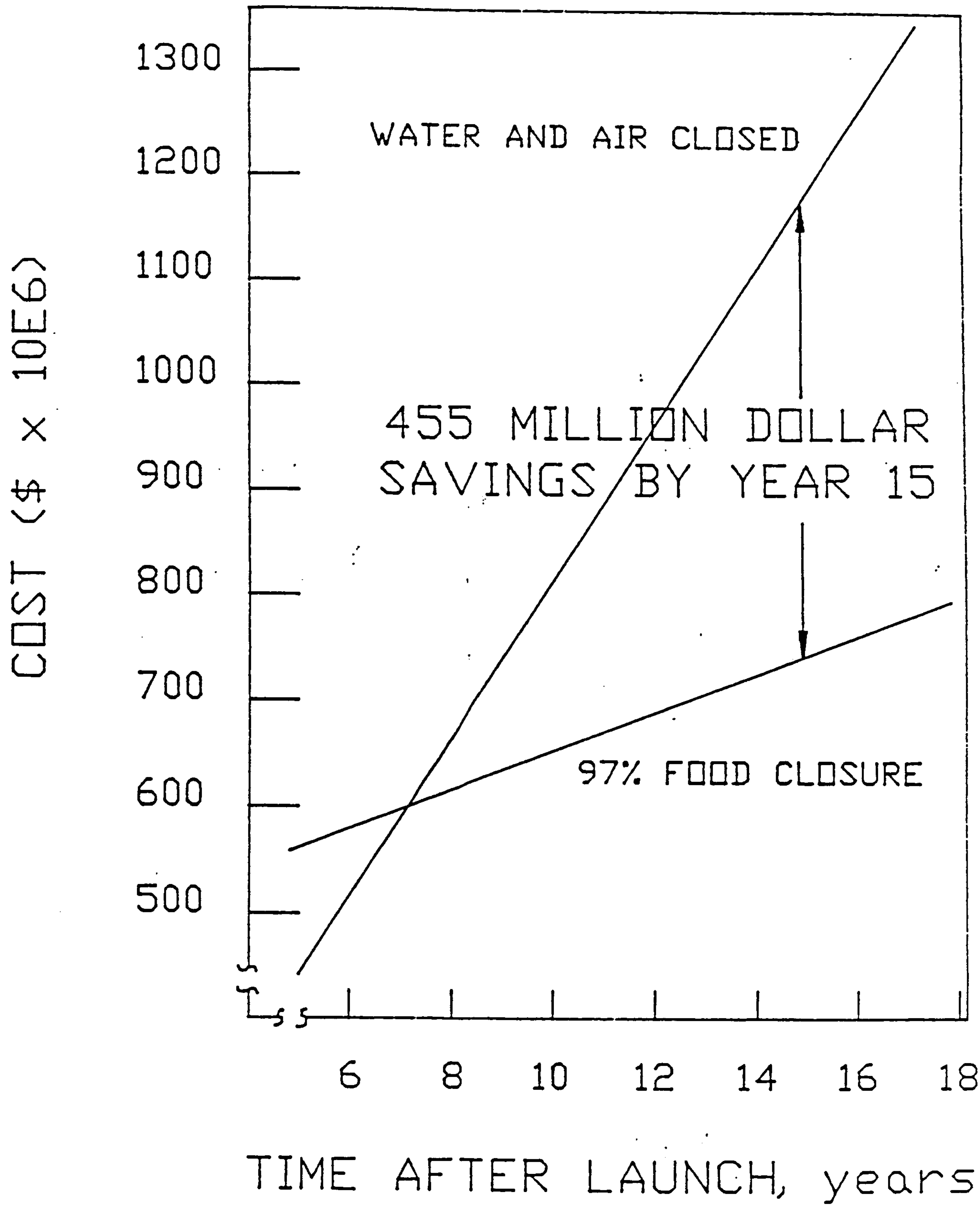


Adapted from: MacElroy et al: Evolution of CELSS for Lunar Bases, In "Lunar Bases and Space Activites of the 21st Century", W.W. Mendell,

Figure 11.

COST SAVINGS WITH CELSS MISSION

(12 MEN)



Adapted from: Gustan et al; Controlled Ecological Life Support System: Transportation Analysis, NASA CR 166420

Figure 12.

The criteria used in choosing the particular species include growth rate (high), hardiness (high), nutrient value (high), processing requirements (low), storage potential (high). The lower plants fulfill the oxygen and food mass requirements, yet they require water purification, extensive processing before edible, and provide only limited nutrients.(A Geosynchronous Space Station: Year 2005, spring 1985)

Higher plants are included in the system as they are necesary to help close the loop; they provide vegetables and variety to the crew's diet, they provide nutrients unobtainable from the lower plants, they provide a back-up system for oxygen regeneration. The criteria used in choosing the higher plants are the same as the lower plants, but more emphasis was placed on nutritional value and palatability than storage and hardiness. (A Geosynchronous Space Station: Year 2005, spring 1985) The plants chosen are soybeans, potato, broccoli, spinach, and wheat. The higher plants will purify the water, are more palatible, require more care and space, require less processing to be made palatible.

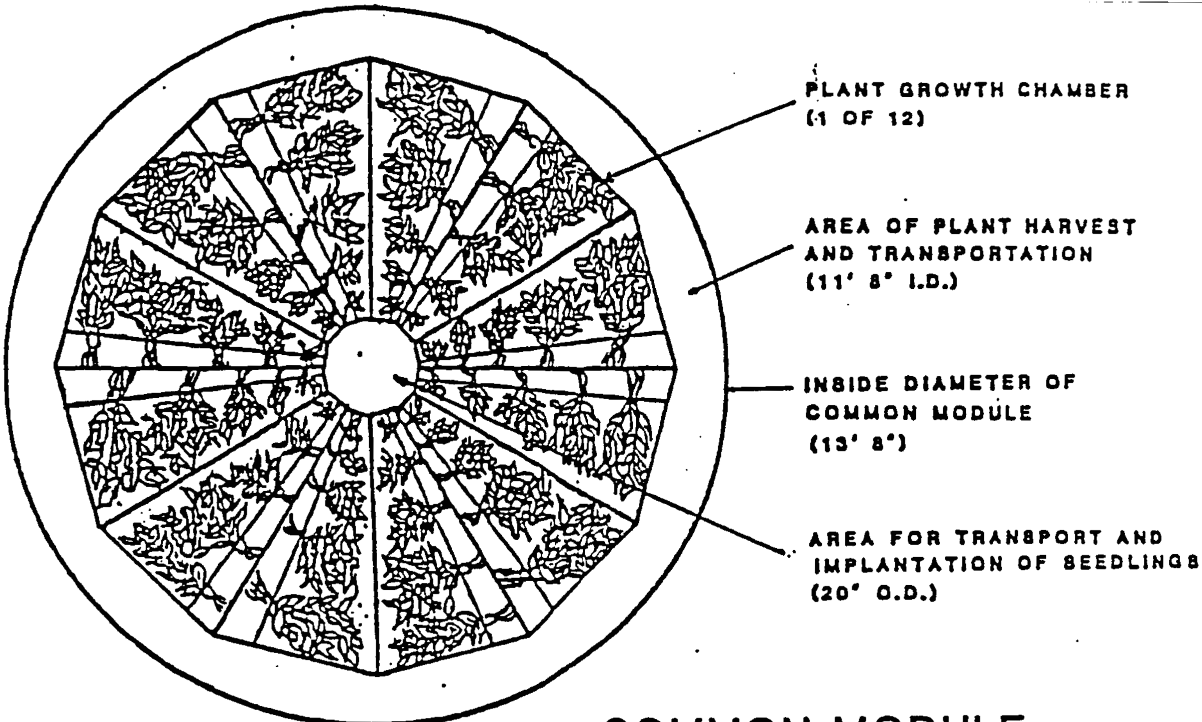
The actual plant growth chamber has also been examined. It is a component of the CELSS that has very specific requirements. This chamber must separate the root and shoot of the plant as each contains elements toxic to the other. It also must grow as the plant does to minimize space requirements and maximize efficiency. A wedge chamber with a zipperseal membrane has been chosen. (Knox, 1986, Appendix A) The plant will move through the wedged growth chamber using only its required space at any particular time. The zipperseal membrane will separate the root and shoot environments and allows growth and motion of the plant stem.(see fig. 13)

Aquaculture is also included in the system. Animals are desired to provide nutrients and variety not available from the plant cultures. Aquaculture, in particular, was chosen because the animals weigh less than five kilograms. Small animals require less volume, are easier to transport to orbit, and require less care. In general these smaller animals also have a higher fecundity and faster growth rate than larger animals; this results in greater stability of the system. The animals chosen are from the Mollusk, Crustacea, and Bony Fish catagories. The animals are a good source of protein, vitamins, minerals, they do however make the system more complex. (Long Term Space Habitation; A Geosynchronous Space Station: Year 2005, Part II ,1985, Appendix B)

Once the components of the CELSS have been determined, the crew, lower plants, higher plants, and aquaculture, their interaction and, duties, and requirements can be examined.

The operational scenario of the life support/CELSS system begins with the crew. Their needs and requirements are first. Once supplied with the necessary food and oxygen, these humans will output solid, liquid, and gas waste products. The solids and liquids must be broken into mre basic materials that can be processed through biomass conversion. These basic materials as well as the spent air can then be processed by biomass conversion. Through the biomass conversion, clean air and a harvest can be produced. These in turn supply the crew with the necessary food and oxygen to survive. (see fig. 14)

The CELSS is one integral portion of the life support system. It is, however, important to note that there is currently no CELSS capable of performing the duties required by GSH under its limitations. GSH is an ideal situation in which to test the new CELSS technologies. As resupply is

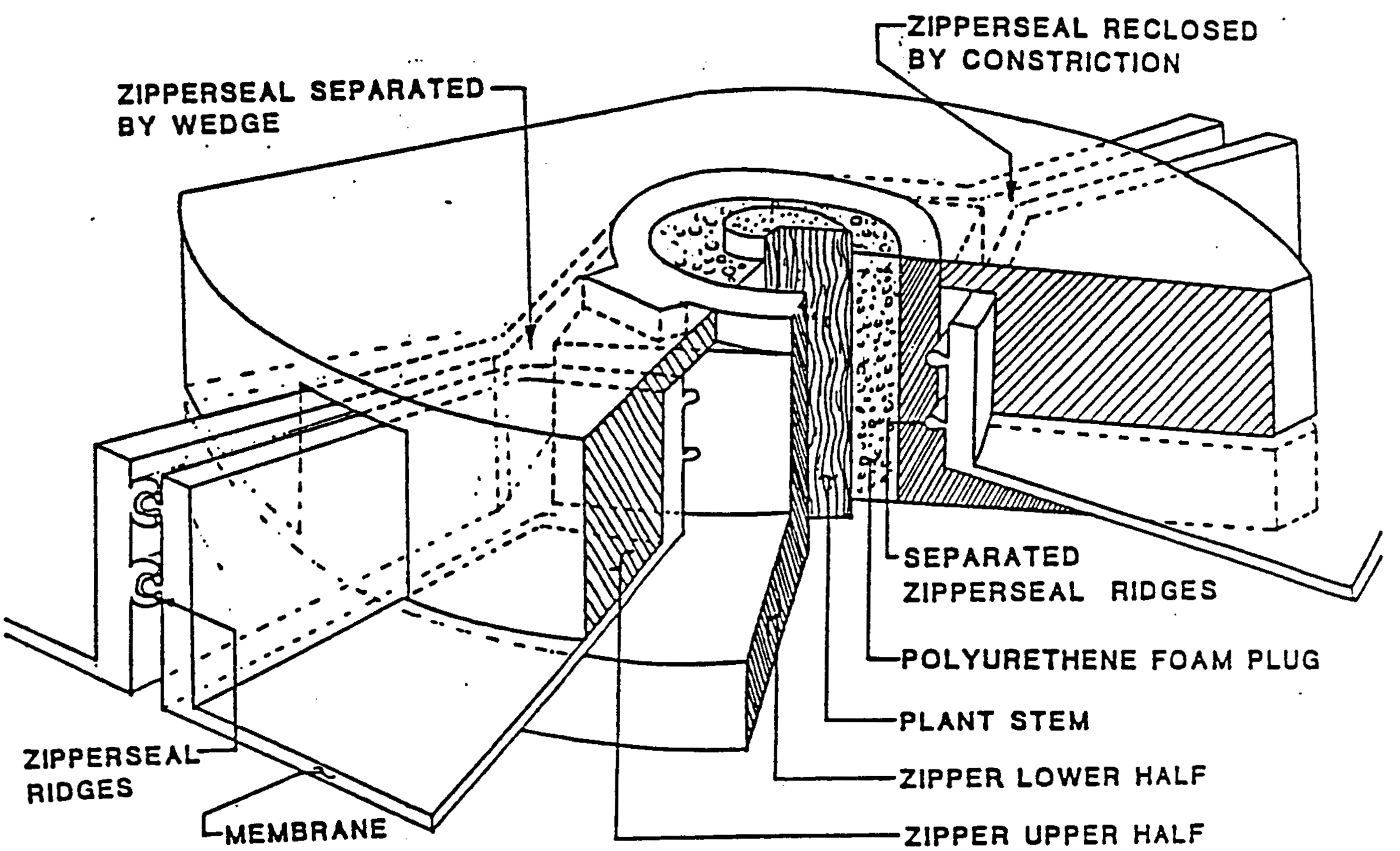


COMMON MODULE

CROSS SECTION

Knox, 1986, Appendix A.

PLANT RETAINING ZIPPER



Knox, 1986, Appendix A.

Figure 13.

MATERIAL CYCLING IN A CLOSED ECOLOGICAL LIFE SUPPORT SYSTEM, OR CELSS

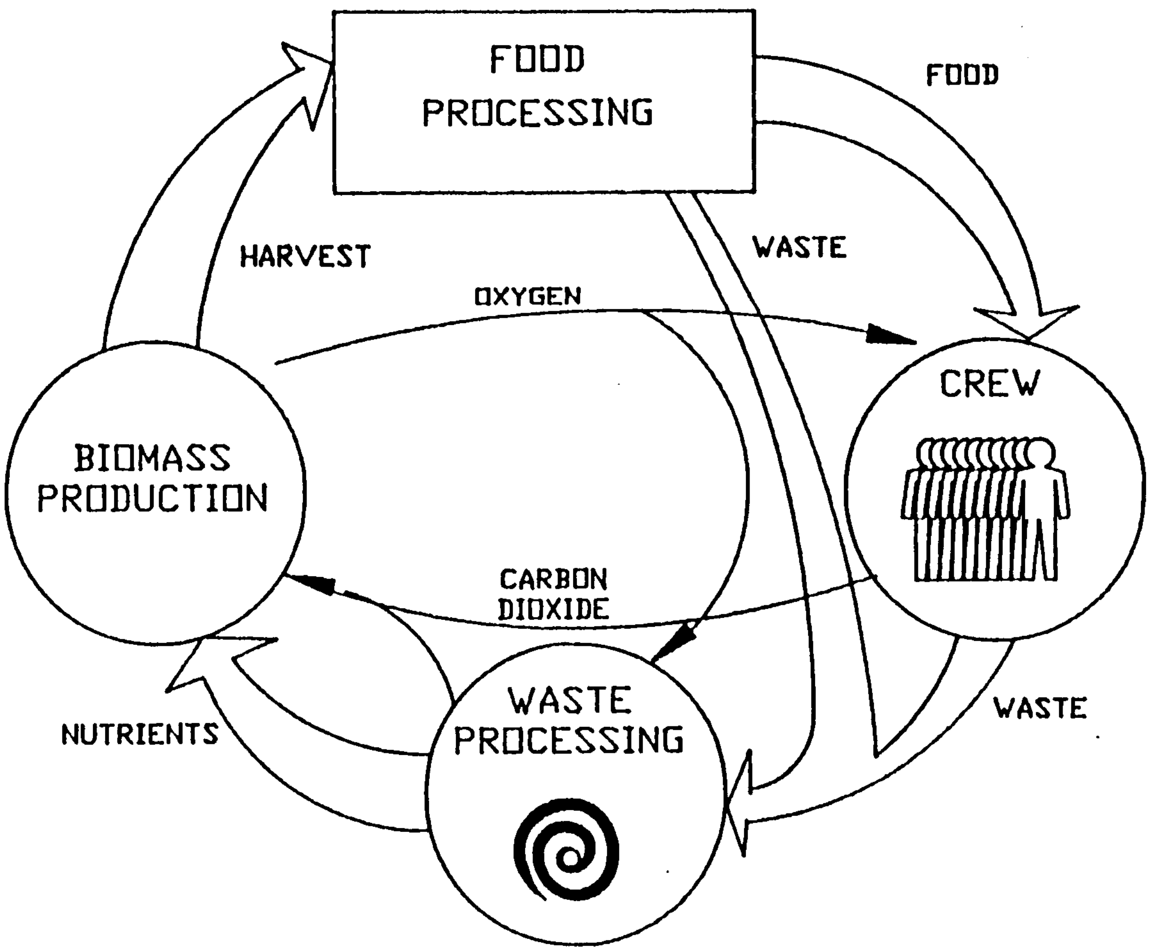


Figure 14.

possible every six months, the system can be analyzed and it can easily be determined what its needs are. In this manner the requirements of a CELSS can be better defined. The knowledge gained from geosynchronous orbit can be applied to future missions into deep space.

Health Considerations, Mental and Physical

Health considerations are also very important. Unlike the shuttle where people only encounter the microgravity, environment for short periods of time, on the order of a week, stays onboard will be six months. Repeat missions will easily result in the equivalent of years of space exposure. As previously mentioned, there are many acute and long term effects of a microgravity environment on human physiology. The effects vary from the short term symptoms of the Space Adaptation Syndrome to the detrimental effects potentially resulting in permanent bone calcium loss or kidney malfunction.

The induced artificial gravity eliminates nearly all of these worries. In addition, the crew productivity will be raised through the gravity environment. There is less time spent adapting physically as well as on a functional level. This productivity shows itself through the time saved by eliminating the need for required exercise and adaptation time. The estimate of 60% of all waking hours (Gardner, 1986, Appendix A) saved by the artificial gravity environment is an important driver in choosing to rotate the station.

Man has never before lived in such an artificial gravity environment. Much as in the microgravity environment, there are many known adverse effects of a radial gravitational force. Coriolis force and gravity gradient, in particular, must be examined as to their effect on the astronauts. Rotating at 0.5 radians per second, neither of these forces will have much of an effect. The Coriolis force is strongest when travelling towards, or away from the access of rotation, but as the station is configured in a torus, motion in this direction is very limited. The difference of gravitational force felt at one's head as at one's feet is minimal, 0.6 % less. Again, this is an acceptable level.(Rose, 1986, Appendix A)

Another health concern is food intake. To survive man must have a certain amount of water and food and oxygen (see above), but to remain healthy, he must also receive the proper nutrients.

Protein, g/day	60 +/- 20	
Calcium, g/day	65 +/- 20	
Iron, g/day	6	
Thiamine, mg/day	85 +/- 15	
Riboflavin, mg/day	1.4 +/- .3	
Niacin, mg/day	8.5 +/- 1.5	
L-ascorbic acid,mg/day	30	
Vitamin A, IU/day	4600 +/- 1500	
Total calories/day	2800 +/- 600	(Riley, 1962)

These values vary greatly depending on the mass of the crew member. The given limits are acceptable for crew members weighing 90 to 190 pounds.

Other factors affecting the physical and mental health of the crew are vibration, sound, and light levels. The body and its organs have natural frequencies. Were the station to rotate at any of these frequencies, pain, discomfort, and even damage would occur. The frequencies at which various parts of the body resonate that should be avoided are as follow.

eyeballs	40 - 80 cycles per second	
head	20 - 30	
bladder/rectum	10 - 18	
windpipe/bronchia	12 - 16	
spine	14 - 15	
thoracic abdominal system	4 - 10	
jaw	6 - 8	
inner ear	3 - 4	(Sharpe, 1969)
entire body	3 - 12	(see fig. 15)

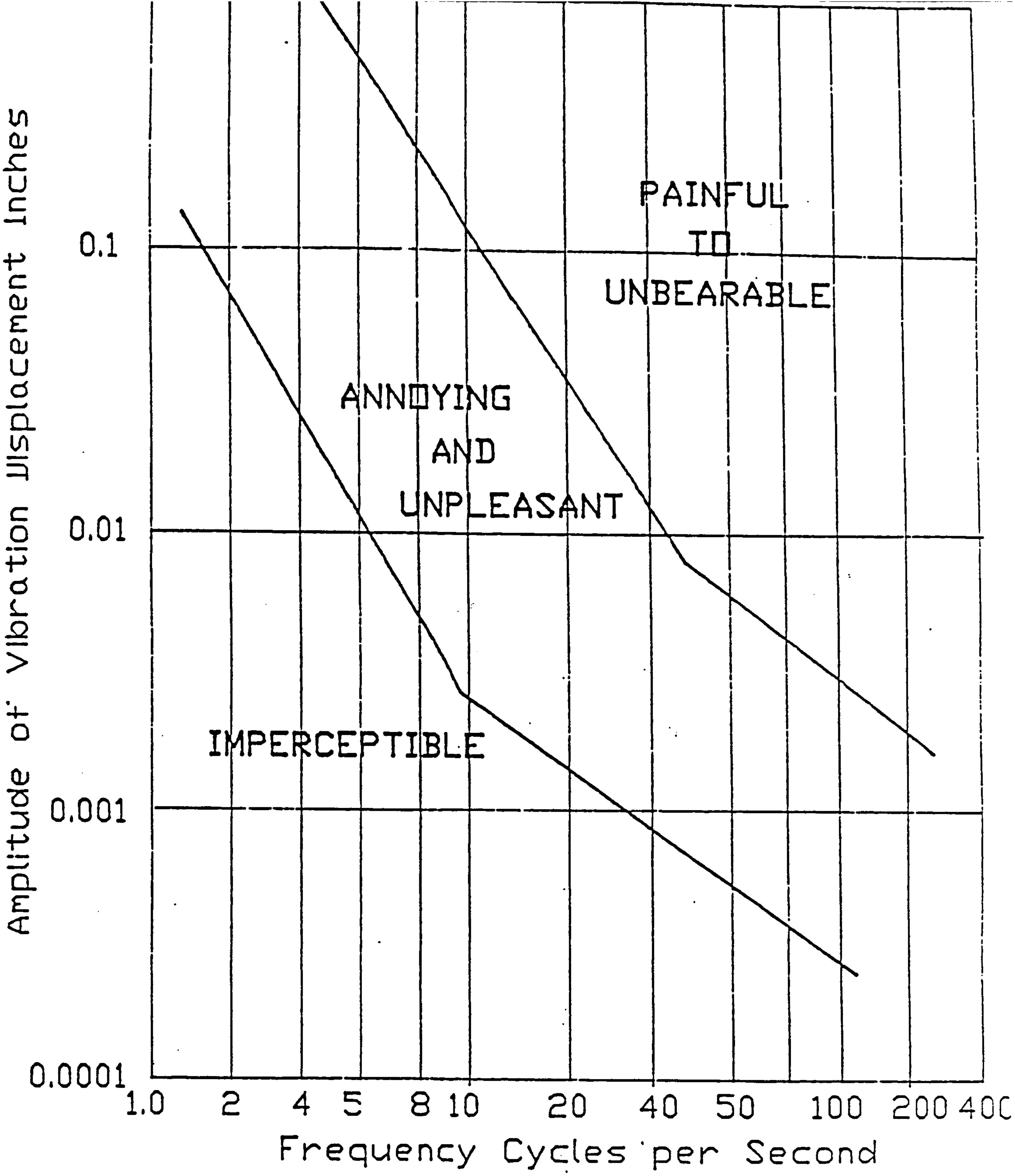
The background noise should be limited to a maximum of 55 db (see fig. 16). The light levels should vary between areas. Halls - 5 footcandles, washrooms - 10 footcandles, living area - 15 footcandles, work areas - 20-40 footcandles.(Sharpe, 1969; Celentano, Amorelli, Freeman). For man to function optimally it is also necessary to provide a proper personal area.

Due to the duration of missions, 4.2 to 5.4 m^3 is a minimum volume. Preferably, this volume will be used not only for sleep but will also be an area in which crew members can read, relax, and work. It is therefore recommended that a volume of 10.8 to 13.5 m^3 be provided. This is about the size of a room, 1.8x2.4x2.7.

The private crew space must allow for personalization. In decorating as well as climate control. Each area should have its own temperature, humidity, light, odour filtration, and air circulation control. Adequate storage for personal crew items such as musical instruments, books, photographs, video and audio tapes and equipment must also be provided.

The entire station must be equiped with good environmental control. Cleanliness: adequate dust filtration means, stain resistant materials, small easily stowed portable vacuums, waste disposal facilities appropriate to each particular form of waste. Acoustics: the walls must be constructed of material that adequately dampen station noises. Lighting: personal control of intensity, ability to alter, add, and remove color,ability to relocate fixtures. Textures: there must be available a variety of non-toxic wall materials to be used for decor alterations. All of these are inexpensive means to provide a changing and stimulating environment for the crew. Electrical: there should be computers and related accessories to allow in room work, communications equipment to contact fellow crew members as well as family on earth, power outlets to accomodate such items as stereo/sound, television, VCR equipment, clocks, coffee machines, andcold food storage.Plumbing: there should be compact bathing facilities, drinking water, and a waste disposal system that removes toxic or unpleasasnt human waste and odors. (Gardner, 1986,Appendix A)

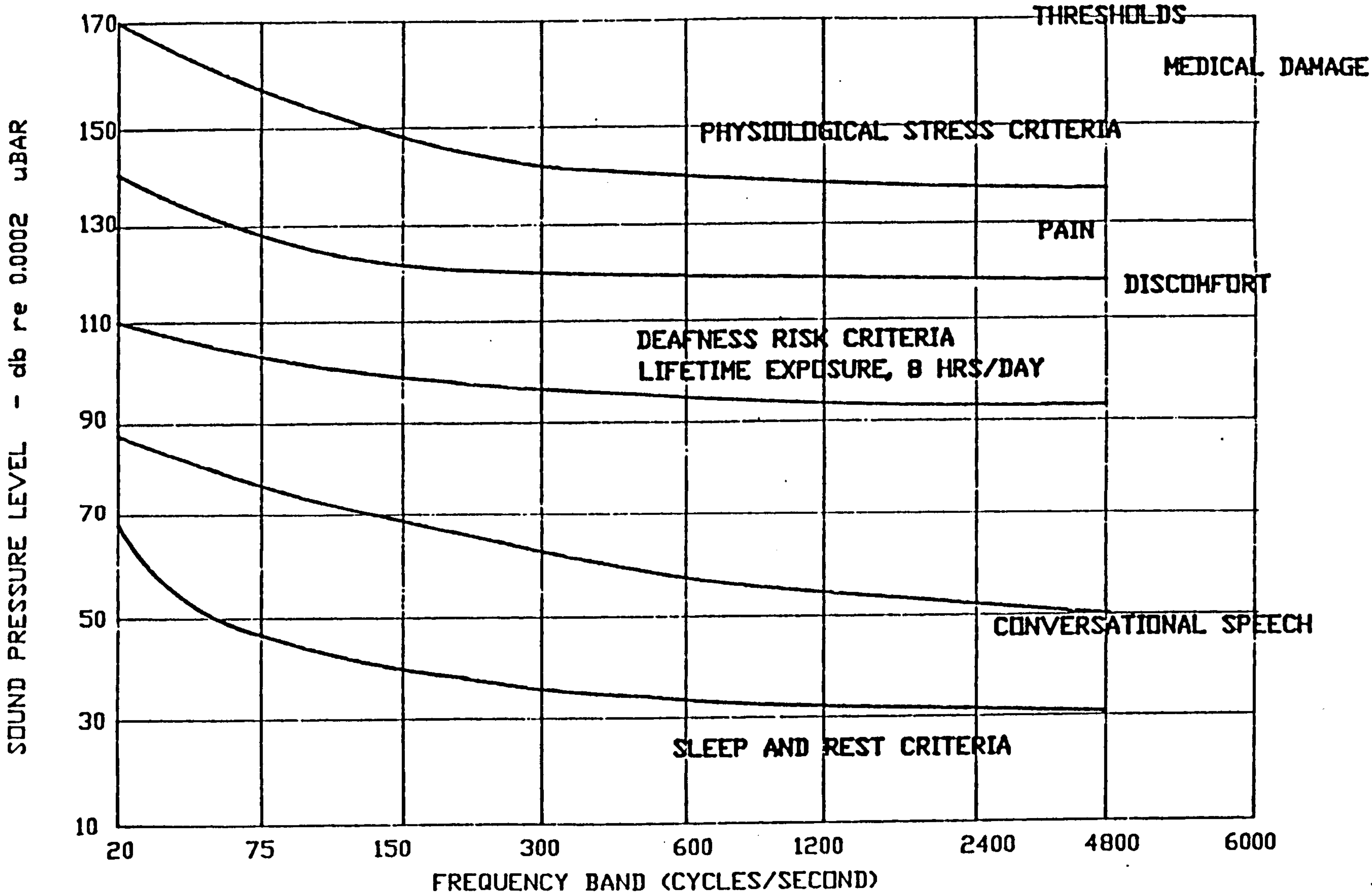
For basic health maintenance aboard GSH, certain medical facilities will be necessary. In particular, certain biological parameters should be measured periodically to record changes, and thereby avoid or correct many problems can be avoided and corrected thorough diet and exercise, or



Limiting Vibration Levels

Adapted from Establishing A Habitability Index for Space Stations and Planetary Bases
Celentano, Amorelli, Freeman

Figure 15.



TOLERANCE CRITERIA FOR NOISE

Adapted from Establishing A Habitability Index for Space Stations and Planetary Bases
Celentano, Amorelli, Freeman

Figure 16.

the use of drugs. The facilities should be able to measure the following parameters:

- respiration rate
- temperature
- pulse rate and blood pressure
- blood content
  - red and white blood cell count
  - hormone levels
  - nutrient and chemical balance (Ca^{++})
- fluid accumulation or loss
- excretory content
  - pathogens
  - nutrient and chemical balance
- bone integrity
- muscle tone and mass
- strength
- endurance
- radiation levels

Other human factors considerations in the internal design of the station include quick access to the medical and emergency equipment, adequate exercise and recreation facilities, ample separation of personal space from work and recreation spaces, maximum tool and equipment accessibility throughout the space operation, most efficient route of utility and mechanical system lines which provide the above accomodations. (Gardner, 1986, Appendix A)

Other specific areas of the life support system that have received only initial investigation, but that are necessary and important subsystems include the following.

- monitoring and isolation of toxins
  - toxins from
    - outgassing of materials
    - combustion thermal decomposition
    - heat vapourization
    - metabolic products of crew members
    - metabolic products of plants
      - algae - Cyanide, Nitrogen Oxides, Ethylene, Ammonia
- required cheating vectors

  The cheating vectors are those supplies that will be sent every six months. They account for the 97% as opposed to 100% closed system.
- fluid transfer and storage
- monitoring and maintenance of
  - thermal balance
  - pressure
- portable life support

- safety and redundancy measures

The life support system of GSH is driven by the humans onboard. Their survival is of utmost importance. However, to make their presence onboard more justifiable it is desired that they exist in a healthy environment. Thus, both physical and mental health measures must be incorporated into the design from the onset.

Robotics

Robotics will be used to automate a large majority of repetitious and mundane operations. Most of the robots will be fairly simple and mission specific. In the beginning, the automated functions will be performed by fixed or mobile robotic arms guided by telepresence. This specialization will make the robotics sytem initially expensive, but when it is compared to the cost and time of employing an astronaut to accomplish a similar task, the robotics system is very cost effective for the long duration of the GSH mission. NASA figures indicate that human work time in space is five times more expensive than that of automated systems. Automation can also increase the speed and efficiency with which many tasks can be accomplished. In the case of GSH, robots will be implemented primarily to facilitate the operation and management of CELSS and to perform EVA tasks.

Economic expenditures are a major concern, but human health risks are a greater concern. EVA is very dangerous to human beings especially during times of high solar activities. The life support equipment, space suit, and communications equipment must all be able to endure solar radiation. Safety requirements on EVA equipment will be very strict, subsequently increasing the cost of the equipment. Also, external repairs on a spinning station will be considerably complex. It will be very easy for an astronaut to become disoriented and lose contact with the station, drifting out into space. EVA robots can be attached to the station and will be constructed of radiation hardened materials, alleviating the radiation danger to humans.

Using robotics and general automation can streamline the basic functions of the station in the face of crew changes. Each new crew member will undergo a period of space orientation for the operation of GSH as well as the space environment itself. The automation of basic functions will allow new crew members to learn while not endangering the station or other crew members. The overall safety and efficiency of the station will be increased because machines may be programmed to carry out their duties and will not forget, or become apathetic about, even a simple task such as checking oxygen levels. The capability to accomodate varying expertise levels will allow the station to be used by crew members with lesser levels of technical training. The automation of routine tasks reduces the necessary time and cost of astronaut training down on earth.

Robots can be used effectively for various necessary tasks on and about GSH. CELSS is a prime example for which the application of robotics will be essential. A CELSS 'farmhand' can be used to perform physical harvesting of crops, manipulating plants within a growing tray, cleaning the growing medium, and other necessary physical manipulations in the system. Since CELSS is ideally a 97% closed system, robots offer the chance to minimize human contact and therefore preserve the purity of the ecosystem.

The goal for the automation of GSH is a symbiosis of human and robot. Because many GSH tasks involve long hours and tedious chores, robots can be utilized in order to free the astronauts for more creative, thinking oriented duties. Consequently, tasks will be completed on a more efficient and thorough level using an automated, robotics system.

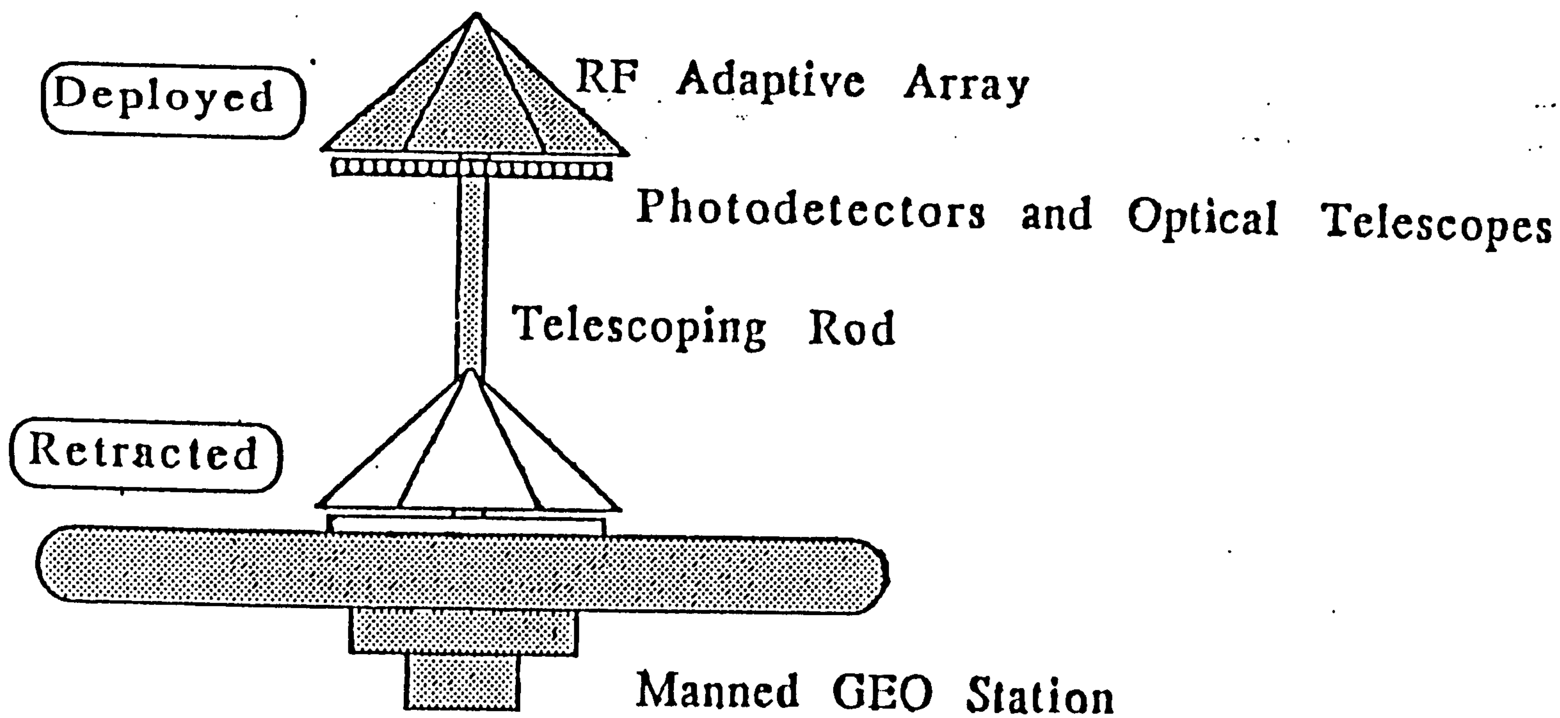
Communications

Even though GSH will be as autonomous as possible, the needs for high quality communications must definitely be considered. Future uses of GSH will mandate the development of deep-space communications capabilities. Present uses simply require communications systems that can link up with earth, the moon, and other orbiters. However, this is a deceivingly complicated task in the 2010 GEO scenario. Complexity arises mainly because GEO provides global coverage with only 3 satellites as well as a characteristic 24 hour orbit. Consequently, satellite systems in this orbit provide relatively inexpensive global coverage and are easy to track and communicate with. These characteristic advantages will create many downfalls for GEO users in 2010. Presently, there are 190 operational satellites residing in GEO, by 2010 there may be as many as 500. Such popularity of this orbit will cause frequency congestion and radio frequency interference (RFI) problems and limited throughput possibilities.

The communications systems of GSH will be state of the art, hybrid tehchnologies combining both millimetre wave (MMW) and optical communications techniques. (Conley, 1986, Appendix A) In order to transfer data for its own purposes and pipeline data from the free flyers, GSH will use high data rates up to 500 Mbps at a frequency of 50 GHz. Such high rates can be supported by the proposed technologies as both will be capable of frequencies as high as 100 GHz with corresponding bit rates of 1 Gbps. Each technology must be analyzed to understand the advantages and disadvantages. An optical communications link will provide nearly 100% accuracy with total security while MMW will provide almost 98% accuracy with nearly total security. Which technology is used will depend upon the hardware available to the user and environmental conditions present at GEO and on the earth. MMW suffers severe attenuation through the earth's atmosphere, whereas laser communications do not. MMW is also subject to RFI. However, MMW is currently more efficient (60% vs 25%) and has a longer lifetime that lasers (15y vs 10y). Lasers, on the other hand, have light, compact hardware. Comparably capable optical equipment can be as much as 15 times lighter than MMW hardware.

With these two technologies in mind, the GSH communications scheme will be a combination of both laser and MMW technology. The hardware for this system will consist of a conical radio frequency antenna and a hoop of laser telescopes. (see fig. 17) This apparatus will be mounted on telescoping rod on the side of the station opposite the docking facility. This rod allows a 30 m extension of the communications apparatus to accomodate a wide field of view at all times and combat the problems of strucural blockage. Besides increasing the field of view, the rod allows the apparatus to be pulled in towards the station during meteoroid showers or times of high solar

Nominal Antenna Configuration



activity. Thus, the sensitive, costly equipment is protected from circuitry burnout caused by radiation and overall damage from meteoroid strikes. The RF portion of the communications equipment consists of 8 triangular panels, 9.144m on the base and 13.716m in height. Together, the panels form an octagonal cone that is 9.881m high and 21.34m in diameter. Each panel contains 36 primary antenna elements, 10.0cm in diameter, with phased array feeds and independent gimbal systems. There are also 78 auxilary elements, 5.0cm in diameter used to distinguish between noise and signals. The optical portion of the apparatus consists of a 'wheel' 20m in diameter, with 8 independently gimballed clusters. Each cluster contains a transmit telescope, a receive telescope, and a beacon laser. The receive device is a 62cm telescope high data rate photodiode with a 100 microradian FOV. The receiver will use a combination of sequential scanning resulting in pointing errors of only 6 microradians. The cluster will also contain a control transmitter to serve as a beacon laser. Using pulse interval modulation, the control will distinguish between noise and photoelectrons, for essentially noise free reception eliminating the problems of gimbal noise.

Since both technologies are viable for GSH, which technology will be used will depend upon the atmospheric condition, security demanded, environmental constraints, that is, how many satellites will be transmitting simultaneously, and the hardware of the receiver. For example, GEO-to-earth DOD communications demanding high security and accuracy will be optical communications. Science transmissions, demanding less security, may be less expensive, MMW communications. If atmospheric turbulence renders optics impossible, high frequency MMW of 50 - 100 GHz may be used for secure, RFI immune communications. For any satellite-to-satellite communications, laser techniques will be used because of the subsequent power and cost savings. Optical communications require 80% less power than MMW to operate a space-to-space link and are therefore less expensive. Under any circumstance, communications will always be possible. The communications system of GSH will never be inoperable because the dual capability nature provides both redundancy and versatility.

Control Systems

GSH is an extremely complicated endeavor. It requires the coordination and integration of many independently complex systems. The control mechanisms for these separate systems must not only monitor the functioning of each independent system, but they must also respond such that the systems are combined and coordinated for optimum operation. It is the responsibility of the control systems (CS) to maintain smooth, efficient, failsafe operation of GSH.

In order to maintain the operational integrity of GSH, it will be necessary to implement control mechanisms that are highly fault tolerant, flexible, and transparent to technology. Fault tolerance will be the highest priority due to the expense and delicacy of the mission. In other words, cost must be minimized; however, the quality of life must not be compromised. The CS must provide automatic fault detection, isolation, and recovery as well as fail-safe/fail-operational performance. This means that in the advent of one CS component failure, the control paths will be rerouted and alternate systems will takeover. All functions will still be performed correctly. In the event of two failures and recovery is not possible, the CS will revert to fail-safe mode and operations will continue on a limited basis. Further, CS flexibility will be demanded in order to make GSH efficient. Flexibility will allow for the addition, deletion or modification of any station sub-system without disturbing the overall framework of the overall system. In addition, this flexibility will greatly facilitate technological improvements and replacements of obsolete equipment, thus making the CS transparent to any further technological advancements. These three specifications will render a generic, versatile control system that will monitor any station operation both now and in the future.

To further enhance the CS structure, all CS networks will consist of hierarchically linked networks of distributed controllers. (see fig. 18) All system purposes are defined and based on the importance of the system to the mission of GSH, the systems are categorized into critical, semi-critical, and non-critical. These categories of systems are then broken down into a group of smaller, more manageable subsystems. This hierarchy will provide a central coordination of a distributed network of sub-controllers. In this manner, the overall control problems are broken down into a network of sub-problems for which design and implementation of a CS will be relatively straightforward.

System categories are formulated according to the mission of the system being controlled. Critical systems are those for which loss of control is life threatening within a short period of time. These systems, which include life support, radiation shielding, power, and CElSS, are highly distributed. Failure in any one of these systems is unacceptable. So, due to the high degree of distribution within these systems, single point failures can be avoided through automated reconfiguration of the failed nodes. Hence, the fault tolerance of these systems is increased to the point that if a problem does occur, the microprocessors will detect the failure and then automatically reroute the CS command flow so that the failed area is avoided, but the system is still being correctly controlled through an alternate route. High distribution also tends to increase the redundancy of the system as well as create a network of passively stable systems, that is, failures affect system performance, not survivability. Semi-critical systems will not be as highly distributed as the critical systems due not only to the cost, but the fact that these systems are inherently stable. In other words, any loss of active control is not life threatening in the short run. These systems include attitude control, structural control, and thermal control. Non-critical systems are basically mission specific systems such as communications, traffic control, station keeping, robotics, manufacturing, and store/inventory. Any decrease in control capability of these systems will not be life threatening. Although these systems are termed 'non-critical,' this is indicative of their ranking within the control command structure, not of their purpose to the GSH mission.

All three systems, critical, semi-critical, and non-critical, have several characteristics in common. These characteristics promote the versatility, adaptability, and failure resistance of the CS. First of all, reliablity is featured by each system due to redundancy, stability, or distribution. Further, efficiency of the CS will be facilitated by using systems that are flexible and modular. Consequently, reconfiguration and improvements at any control level will be much cheaper and easier. This will allow for any new mission specific mechanism to be quickly integrated into the existing system without disrupting the control flow. Since safety of the crew is imperative, all the

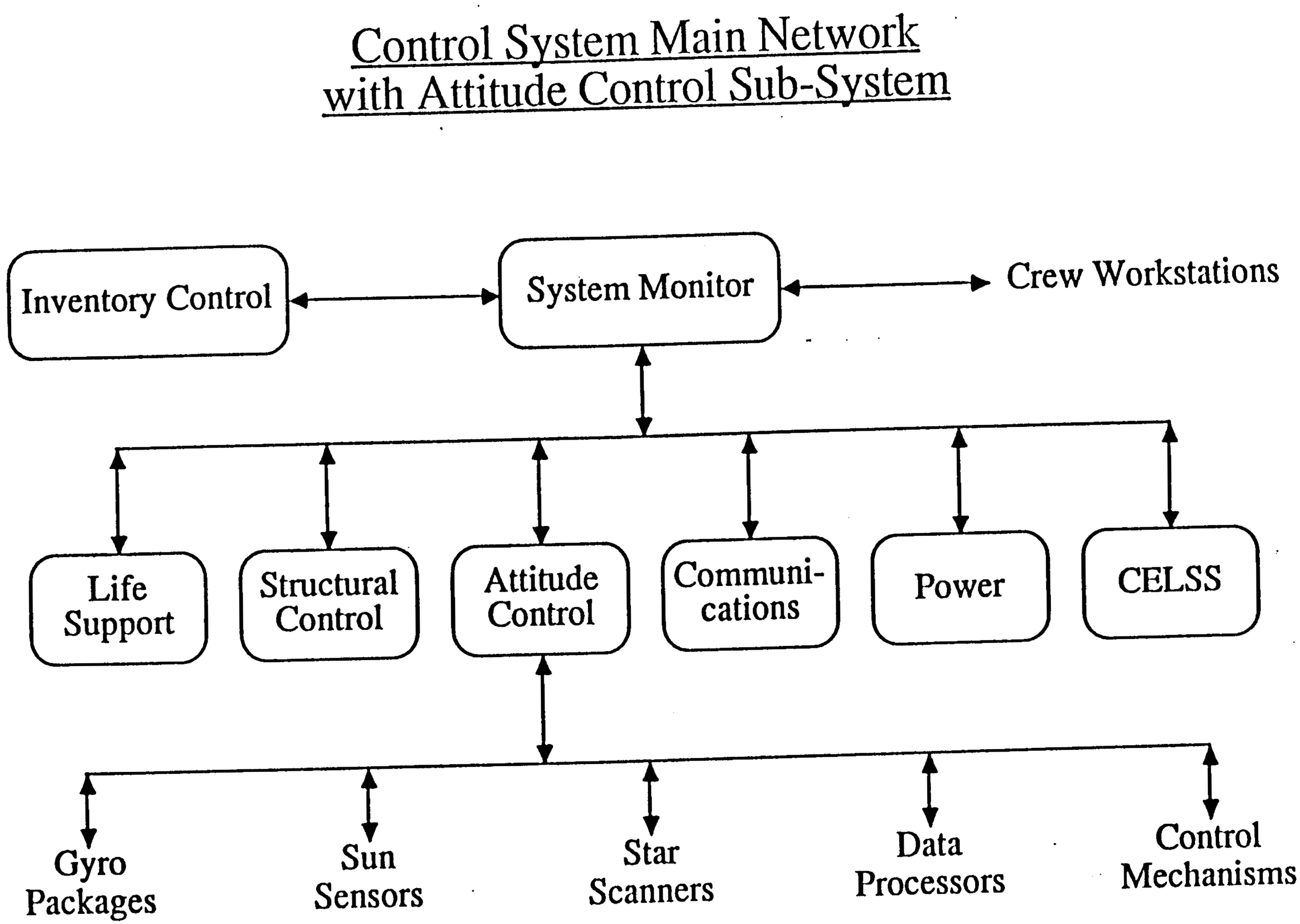

Control System Main Network
with Attitude Control Sub-System
Inventory Control
System Monitor
Crew Workstations
Life Support
Structural Control
Attitude Control
Communi-cations
Power
CELSS
Gyro Packages
Sun Sensors
Star Scanners
Data Processors
Control Mechanisms

Figure 18.

control systems will queue backup means of operation in the occurance of failures. In the end, it will be the proper integration of all three categories of control systems that assures the safety and welfare of both the astronauts and the GSH.

As was previously mentioned, the CS are broken into three categories, critical, semi-critical, and non-critical. The required specifications of each have been noted and explained. Now, each system will be described in further detail in order to demonstrate its role in meeting the specified objectives of the GSH.

Radiation, power, life support and CELSS comprise the critical systems category. Each system plays an integral role in the survival and maintenance of the optimal health of the astronauts. Obviously, the driving force for all systems on GSH is power. Absence of a power source would make GSH a technological impossibility. Factors with which the Power control system (PCS) will deal are the spacing of the power satellites with respect to GSH, the pointing of the power receiver, the storage of reserve power, and the budgeting and regulation of power production. During normal operations, the PCS will provide all working systems with 100% of the required power. In the case of a crisis, the PCS will alot power accordingly so that the most efficient operation under the existing conditions can take place. This way, all critical, life-vital systems will continue functioning.

Radiation shielding, which will be accomplished by the use of a plasma shield, is a complex control situation. The plasma shield control system (PSCS) must first monitor data about the sun's activities according to the electron flux and sun spot data. From this data, the microprocessors must check the super conductors and field conditions to see if 1) they are of the right magnitude to protect GSH from the GEO atmosphere, 2) they are in operating condition. Then, the processor must check to see of the power being delivered to the system is appropriate, if not, the condition must be corrected. After the hardware is checked, the PSCS must them monitor plasma distribution to ensure that it is mot 'clumping.'

Perhaps the most critically vital system to the survival of the astronauts is the life support control system (LSCS), without it, death would be immenent. LSCS will automatically regulate the atmospheric partial pressure, cabin temperature, contaminants, lighting and humidity. The desired values will be those deemed necessary for the premium health and performance of the astronauts. Based on the values noted in the Life Sciences chapter of this document, the LSCS must regulate these delicate values within the acceptable ranges, that is, cabin temperature: 21+-5 deg. celsius, cabin pressure: 500+-100mmHg, nitrogen: 110+-5mmHg, oxygen:400+-10mmHg, and CO_2:4+-1mmHg. In order for LSCS to regulate these factors, LSCS must interface with the thermal control system and the CELSS control system .

Whereas life support maintains adequate living conditions for the astronauts, CELSS is responsible for complementing life support by generating all the necessary natural nutrients for human, animal and plant life. CELSS is necessary in order to create a nearly autonomous, self-sustaining environment within GSH. The CELSS control systems (CCS) will be extensively integrated with LSCS since CELSS will be responsible for supplying the life support systems with oxygen, nitrogen, and food products while life support will supply CELSS with byproducts to recycle. The task of CCS will be to control this cyclic equilibrium such that production equals consumption.

The second category of systems, semi-critical, are the attitude, structural, and thermal control systems. Although failure in any one of these systems is not immediately life threatening, failure is not desired. These systems must still be regulated continually so that the mission succeeds. First, the structural control system will be responsible for maintaining the dynamic stability of GSH. That is, vibrations and deformations will be minimized. As well as vibrational deformations, static deformations must be minimized. These deformations occur due to the heating of the sun which tends to 'curl' the structure. Second, in order to counteract the various movements occuring due to humans, animals, and EVA, which can affect the attitude and orbital stability of the station, the attitude control system employed must continually monitor the CG location, the spin vector, and the spin rate as defined earlier. Third, the thermal control system (TCS) is the last semicritical system of GSH. Considering the fact that heat is produced by the biological systems, the mechanical systems, and the sun, this is not a trivial task. The control systems for thermal factors must always maintain the desired interior temperature within a range of +- 4 degrees celsius. To keep such a steady temperature, the TCS must receive data from PCS, ACS, SCS, and CELSS. This way, knowing the power being supplied, the position of the sun, and the output of the environment, the TCS can enact the waste heat mechanisms to properly maintain a comfortable atmosphere for the astronauts as well as the electronic equipment.

Structural and attitude control are very interrelated. One such example is the despun docking facility. The despun sections must be monitored so that any manuevering will not affect the overall stablility and orbital attitude of GSH. Directly, the despun docking control system will control the spin up and spin down of the sections by controlling the speed of rotation and bearing positions. This data must in turn be fed to the structural control mechanisms so that structural integrity can be maintained during all operations, that is, deformations and vibrations will be minimized. After the structural data has been obtained, the attitude control system can be activated so that the GSH orbit and relative position are constant despite the activities onboard which may alter the location of the center of gravity. Feedback will continually be given to both the ACS and SCS during any docking operation. The output from these two systems will affect the feasability of any docking procedures.

The last category of control systems is non-critical. The control of these systems is relatively centralized when compared to the critical and non-critical systems. Controls will basically be handled with equipment specific to the systems modular unit or hardware. One distinct advantage, however, of these sytems is that because they are at the end of the command flow, alteration is very simple. Any new experiment or communications need can be added easily. Due to the expandability of these systems, the missions of GSH can be increased greatly. New experiments or systems can be incorporated at any time during the operational lifetime of GSH.

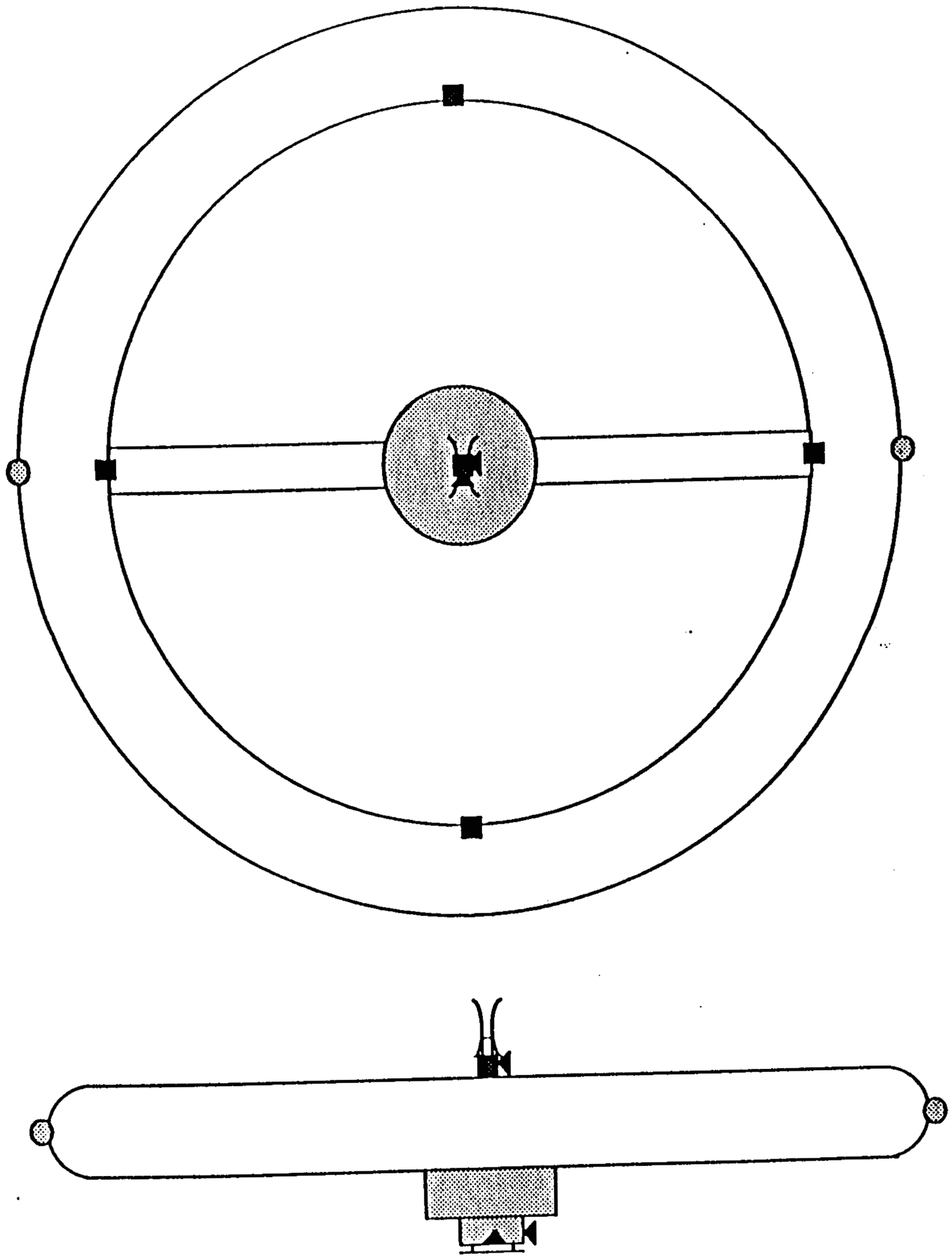
Inherent in the proposed design of GSH is a viable attitude control scheme. The question of whether or not the proposed design was reasonably controllable and stable had to be answered before settling on a configuration. As it turns out, the proposed design is relatively stable as a spinning station. The attitude control needs concern several factors. The first task is dynamic balance or control of the location of the center of gravity. Wobble can occur due to live loads and thermal and vibrational deflections which cause the nominal axis of symmetry to no longer be the principle axis. Wobble may also occur due to changes in the CG during docking manuevers or EVA. Also, the spin vector must be controlled in order to maintain acceptable levels of coning, nutation, and attitude bias. Control will be provided by passive nutation damping and momentum transfer devices. A momentum exchanger will also lend itself to controlling the spin rate. Spin rate control will occur through desaturation of the momentum exchangers using thrusters. Ideally, all attitude control aspects will be as passively stable as possible so that stability is inherent in the design making failure less likely to occur.

Since the precise needs of the attitude control system have been defined, the mechanisms of control may now be discussed. Several possibilities exist to complete this task. These are magnetometers, horizon (earth) sensors, star trackers, star scanners, and sun sensors. Due to the proposed construction and operation of the station, magnetometers are pointless hardware because of the plasma shield. With the intense magnetic field requirements of the shield, it is impossible for the control device to find a 'natural' field, so, magnetometers are rendered useless. One of the requirements for GSH stability is a rotation of 5 rpm or 12 degrees/sec. Because star trackers can track at only 0.5 - 1 degree/sec, these sensors are also unfeasable for the GSH. In addition, star trackers are heavier and nearly twice as expensive as star scanners. The two most likely possibilities for GSH control mechanisms are star scanners and sun sensors. Both are simple, non-mechanical devices. Star scanners are very accurate and rotation dependent, in other words, they need to be spinning to function. Sun sensors are less expensive but not as accurate. Their field of view (FOV) is limited to +- 64 degrees with an accuracy of +- 0.5 degrees. The limited FOV can be overcome by mounting several sensors which give overlapping coverage.

For use in GSH, a system of gyro packages, star scanner packages, and sun sensors will be implemented.(see fig. 19) A multiple device scheme such as this affords GSH with an attitude control system which is redundant, accurate, and has a lifetime of and anticipated 30 years. To begin with, the gyro packages offer a continuous source of inertial attitude knowledge. The package combines rate gyros and rate-integrating gyros for a high degree of accuracy. Therefore, a lot of redundancy is present. And, by distributing these packages, a proper blending of the signals can result in a suppression of the disturbing affects of the dominant structrural modes on sensed body angles and rotation rates. Like the gyro pakcages, the star scanner packages are also internally redundant. In addition, these packages use solid state detectors which increase their longevity three-fold. The biggest advantage of the star scanners is their compatability with the spinning station. This is because the star scanners must themselves be rotating in order to scan the viewing strips through a star field. Thus, star scanners fit right into the GSH program. Lastly, sun sensors will be on board as a backup attitude source. They too will be of solid state construction.

In view of current technology, this type of attitude control scheme is possible. By the year 2010, possible developments towards better laser gyros, sperical resonator gyros, and deep space, astroidal positioning will make the ACS more reliable, accurate, and less expensive.

While the individual control mechanisms for each system will be specialized, the entire control network structure is very orderly, versatile, and generic. This sort of adaptable system will lend



Attitude Determination Hardware Summary

LEGEND:

- ◀ Star scanner package
- ■ Gyro (rate/rate-integ.) package
- ● Sun sensors package

Figure 19.

itself favorably towards use on long-term, dynamic missions in space where new technologies may be continually integrated and mission needs varied. While the centralized, hierarchical networks may be more complex, the cost effectiveness of using this transparent system is obvious.

Conclusion

The Geosynchronous Space Habitat is one small step in the evolution towards a milestone of United States exploration into space. This project is feasible as it utilizes state-of-the-art technology and forseeable technological advances. GSH satisfies the proposed design criteria. Because of a life support implementing CELSS, man will be able to easily exist onboard the station for six month intervals. Not only will man be able to exist, but the quality of life will also be maintained through artificial gravity. Both physical and mental health will be sustained. Despite the alarming initial cost, the economic benefits reaped from future station uses justify the expense. Satellite repair alone can return 1.6 billion dollars/year. The preceeding preliminary design details the feasibility and specific requirements of a geosynchronous space habitat.